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ABSTRACT

The goal of this resource notebook is to provide activities selected by astronomers and classroom teachers, comprehensive resource lists and bibliographies, background material on astronomical topics, and teaching ideas from experienced astronomy educators. The activities are grouped into several major areas of study in astronomy: lunar phases and eclipses, the Sun and the seasons, the planets, the scale of the solar system, comets and meteors, star-finding and constellations, stars, galaxies and the universe, space exploration and the Search for Extra-Terrestrial Intelligence (SETI), tools of the astronomer, debunking pseudoscience, and astronomy in different cultures. An extensive glossary and a section that provides interdisciplinary teaching ideas are included. (DDR)

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THE UNIVERSE AT YOUR FINGERTIPS

AN ASTRONOMY ACTIVITY AND RESOURCE NOTEBOOK

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THE UNIVERSE AT YOUR FINGERTIPS

AN ASTRONOMY ACTIVITY AND RESOURCE NOTEBOOK

EDITED BY
Andrew Fraknoi

A Publication of

PROJECT
ASTRO

at the
Astronomical Society of the Pacific

PROJECT ASTRO
Astronomical Society of the Pacific
390 Ashton Avenue
San Francisco, CA 94112
415-337-1100
FAX 415-337-5205

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PROJECT
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COVER AND DESIGN
Joan Venticinque

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Donna Kinsler

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Comments Welcome

We welcome your criticisms, suggestions, helpful hints and anecdotes about your experience presenting activities from the **Universe at Your Fingertips.** Please send your comments to: Resource Notebook Revisions, Astronomical Society of the Pacific, 390 Ashton Ave., San Francisco, CA 94112.

THE UNIVERSE AT YOUR FINGERTIPS

AN ASTRONOMY ACTIVITY AND RESOURCE NOTEBOOK

Edited by Andrew Fraknoi

PROJECT ASTRO STAFF
Andrew Fraknoi, *Project Director*
Jessica Richter, *Project Coordinator*
Donna Kinsler, *Project Assistant*

ACTIVITIES EDITORS
Scott Hildreth, *Chabot College*
Joseph Snider, *Oberlin College*

CONTRIBUTING AUTHORS
Cary Sneider, *Director Astronomy and Physics Education, Lawrence Hall of Science, University of California at Berkeley*
Sally Stephens, *Sirius Science Writers*

TEACHER CONSULTANTS
Ann Dee Clemenza
Jim McDonald
David Peterson
Stephen Ruthorford
Christina Wilder

EVALUATOR
Lynn Dierking, *Science Learning Inc.*

REVIEWERS, ADVISORS AND CONTRIBUTORS

REVIEWERS

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Anthony Heinzman, *Apple Valley Junior High School*
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Larry Lebofsky, *University of Arizona*
Jeff Lockwood, *Sahuaro High School*
Gary Nakagiri, *San Mateo County Office of Education*
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Michael Reynolds, *Chabot Observatory & Science Center*
Dennis Schatz, *Pacific Science Center*

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Dennis Schatz, *Pacific Science Center*
Cary Sneider, *Lawrence Hall of Science, University of California*
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ASTRONOMERS

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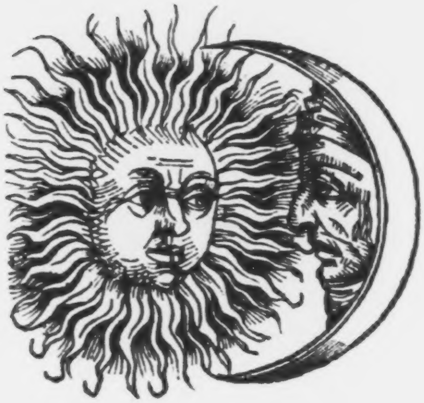

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SECTION AND ACTIVITY NUMBER **GRADE LEVELS**

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12

SECTION

1

INTRODUCTION

THE UNIVERSE AT YOUR FINGERTIPS

AN INTRODUCTION

by Andrew Fraknoi
Director: Project ASTRO
Astronomical Society of the Pacific

Just imagine:

- *a volcano on Mars larger than the state of Nebraska;*
- *a moon around Neptune so cold that even such common gases as nitrogen and methane freeze out as snow and frost (and water would be harder than rock);*
- *a collapsed star so dense that one thimbleful contains as much material as all the cars and trucks in the entire United States;*
- *a "cannibal galaxy" with hundreds of billions of stars which shows evidence of having quietly consumed a small neighbor galaxy "for lunch."*

These are just a few of the amazing objects that our instruments are discovering as we explore the universe. These are exciting times in astronomy: we have sent space probes to seven of the eight planets with which we share our solar system, seeing them and their moons "up close" for the first time. We are putting the finishing touches on a pair of giant telescopes in Hawaii, each of which will be the largest "eye" we have turned to the heavens. At the same time, astronomers are delighted with the repaired and improved Hubble Space Telescope (which, although not as large, has the clarity of vision possible only above the Earth's atmosphere). These and other new instruments promise to give us an unprecedented flow of information about the cosmos in the decades to come. With them we hope to probe even farther out into the distant reaches of space and even further back into the remote reaches of time.

And the excitement astronomers feel is often matched by youngsters. There is nothing quite like the study of astronomy to capture the imaginations of our students and to introduce them to the fundamental ideas of science and mathematics. It is no coincidence that space-oriented films hold box-office records and that survey after survey shows astronomy to be at the top of the lists of topics kids would like to know more about. Children of all ages naturally gravitate to the strange worlds and alien vistas we are uncovering in space and to the thrill of discovering more about our own origins in the life stories of the stars.

Astronomy provides an ideal entree to the methods of science in general. When students begin to understand how we can learn about objects so far away that even their light takes more than a thousand human lifetimes to reach us, they have a demonstration of the power of the scientific method that is likely to remain with them in their other science courses as well.

Many teachers would love to include more astronomy in their classes, but they are often held back because their own background and training in the subject may be weak or out of date. They worry that, without further training, they will not do as good a job in teaching astronomy as they would like to do. Yet how many teachers have the time to spend a semester learning astronomy?

This is precisely where Project ASTRO and *The Universe at Your Fingertips* come in. For the past four years, the staff at the Astronomical Society of the Pacific (ASP) has been preparing and testing a strategy to help teachers who would like to incorporate more astronomy into their classroom (and after-school) work.

THE ASTRONOMICAL SOCIETY OF THE PACIFIC

The ASP is an international nonprofit scientific and educational organization, founded in 1889, whose mission is to advance the science of astronomy and to help disseminate the results of astronomical research to students, teachers, and the public. Begun on the Pacific Coast of the U.S. (hence its name), the Society today has members in every state and over 60 other countries and is one of the largest astronomical organizations in the world. The Society counts among its members not only scientists, but many educators at all levels, active amateur astronomers, and thousands of laypeople with what we call an "armchair" interest in astronomy.

Since 1978, the Society has been offering weekend workshops on teaching astronomy in grades 3-12 at college and university campuses around the country, from Boston University to the University of Hawaii. Several thousand teachers have taken these workshops and returned to their schools with the resources, activities, and information to incorporate more astronomy in their existing classes. Many of the materials and techniques in Project ASTRO grew out of these summer workshops.

PROJECT ASTRO

Many professional and amateur astronomers, concerned about the crisis in science education in the U.S., have wanted to do more to help teachers, but have often been unsure how to make a meaningful contribution. Many astronomers make a one-time visit to a local classroom (often when one of their own children may be in it), but such quick interactions don't turn out to affect student attitudes and interests as much as one might hope.

So the ASP proposed an experiment to the National Science Foundation: to take enthusiasic astronomers (amateur and professional) around the state of California and train them to be effective agents of learning and change in the classroom. We would link them from the very beginning in on-going partnerships with interested 4th through 9th grade teachers, asking the partners to commit to at least four, but hopefully even more, astronomer visits to the school each year. We would provide both the astronomers and the teachers (during training workshops) with age-appropriate activities, resource materials, and examples of effective teaching strategies. Working together, the partners would then lead hands-on activities in astronomy, sponsor "star parties" and other evening programs for families, encourage astronomy clubs and projects, and generally work to increase the quality and quantity of astronomy being taught in their schools.

A pilot program along these lines, which we called Project ASTRO, was funded by the NSF's Informal Science Education Division. We ultimately involved over 45 schools around the state of California, with almost 150 astronomer and teacher participants from 1993 through 1995. The pilot project was a strong success, and has already generated spin-off projects in two California cities, as well as inquiries from around the country. Plans are now underway, with further support from NSF, NASA, and the ASP, to expand the project to other sites around the country.

A very significant part of the project was its emphasis on hands-on activities. We wanted students to discover the ideas of astronomy for themselves, not just to read about or hear about them passively. Thus many sessions of our training workshops focused on such activities, led by

Dennis Schatz of the Pacific Science Center, one of this country's pioneers in using hands-on techniques for astronomy education. The same emphasis is central to this notebook.

From the very beginning of the project, we envisioned publishing a resource guide for participating teachers and astronomers, which would include a wide range of activities, resource lists, and teaching ideas. It is this resource guide that you now hold in your hands (or more likely, given how heavy it is, on your desk). This version incorporates the many things we have learned from the pilot program and from colleagues around the country who have helped us develop and review the material it contains.

THANK YOU'S

The first prototype of *The Universe at Your Fingertips* received very generous support from the Banbury Fund, which has a long history of underwriting innovation in science, medicine, and education. We would like to thank Bob and Kate Ernst for their strong support of the whole project over the years. Additional support came from the Bart Bok Memorial Fund of the Astronomical Society of the Pacific, set up to honor one of the great astronomers of the twentieth century, whose dedication to science education was an inspiration for generation of scientists and teachers.

We have very much appreciated the encouragement and financial assistance we have received from the Informal Science Education Program at the National Science Foundation. Bob Russell, Hyman Field, and Barbara Butler were the original program officers who worked with us. During the second half of the project, we received marvelous guidance and advice from our new program officer Roger Mitchell.

At the Astronomical Society of the Pacific, many officers and Board members have helped launch Project ASTRO. We would especially like to thank Frank Drake, who, while he was ASP President, began our involvement with the National Science Foundation; and Bruce Carney, Jack Newton, and Jeff Lockwood, who actively encouraged us to move ahead with the project over the years.

Many astronomers, educators, and ASP staff members helped with both Project ASTRO and *The Universe at Your Fingertips*, and their names are listed on the acknowledgements pages.

I would particularly like to note the work of:

- Cary Sneider (Lawrence Hall of Science) who wrote the introductions to the activity sections (and other introductory material)
- Scott Hildreth (Chabot College) who wrote the cover sheets for each of the activities
- Sally Stephens (a free lance journalist and astronomer) who wrote the astronomy introductions for each activity section
- Joseph Snyder (Oberlin College) who helped assemble and organize the activities and many other parts of the notebook
- Lynn Dierking of Science Learning, inc., who was our Project Evaluator, and whose suggestions and summary of participant suggestions helped improve the notebook considerably
- Donna Kinsler (Project ASTRO staff) who patiently and skillfully laid out and assembled the astronomical number of pages you have before you; and
- I would especially like to thank Jessica Richter, the Coordinator for Project ASTRO, for all her creativity and hard work in developing and preparing the notebook. Under Jessica's supervision, many of the sections and formats in the notebook were re-conceived and made much more user-friendly than the first prototype. She initiated and organized the process of involving mentor teachers in the selection and reviews of the many activities that were submitted to us. She also developed and managed the process of getting feedback and input from Project ASTRO participants, which helped to

improve the final notebook considerably. And she efficiently coordinated the enormous project of designing and producing the 800 or so pages of masters from which the notebook has been printed.

CONCLUSION

The Universe at Your Fingertips is and will continue to be available through the non-profit catalog of the Astronomical Society of the Pacific. We hope, from time to time, to produce update packages to supplement the notebook and incorporate new developments in both astronomy and astronomy education.

We very much welcome feedback from the readers and users of *The Universe at Your Fingertips* and encourage you to write, fax, or e-mail us with your suggestions, corrections, and additions. Send them to: Andrew Fraknoi, ASP, 390 Ashton Ave., San Francisco, CA 94112. Fax: 415-337-5205. E-mail: fraknoi@admin.fhda.edu.

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We live in strange times: while on the one hand, solutions to the problems we all face on planet Earth demand an increasingly sophisticated understanding of science and technology, on the other hand, the U.S. public seems to know and care less and less about science. The solution to the crisis of scientific illiteracy and apathy in this country begins in our schools, in the grades when students' opinions about science are first forming. It is the hope of all of us who worked on this notebook that, in some small way, it can contribute to increasing the familiarity of our students with astronomy in particular and encouraging their enthusiasm for the methods and discoveries of science in general. For better or for worse, the world we have created now demands of all its citizens an increasingly sophisticated understanding of science and a growing ability to make judgments that involve science.

At the very least, we hope the next generation of students will grow up feeling more at home in this vast, awesome, and exciting universe we all have the privilege to share.

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Photo by Catherine Lombard

HOW TO USE THE UNIVERSE AT YOUR FINGERTIPS

The Universe at Your Fingertips is a key product of Project ASTRO, and has been developed over a period of about five years. The loose-leaf notebook pages contain exemplary classroom activities selected by a team of teachers and astronomers, comprehensive resource lists and bibliographies, brief background material on astronomical topics, and teaching ideas from experienced astronomy educators.

We urge your to leaf through the notebook to get an idea of the rich variety of resources "at your fingertips." You will notice that the notebook is divided into several sections:

- An *Introduction*. Note especially the **activity chart** after the table of contents that lists all of the activities in the notebook with appropriate grade levels for each
- An *Astronomy Background* section with several **articles about astronomy in general for beginners** and a clear glossary of astronomical terms.
- A *Teaching and Learning* section containing two **articles about student learning** and what it means to teach astronomical concepts effectively, along with a **glossary of science objectives** for student learning.
- An *Astronomy Activities Introduction* describing in greater depth how the activities were selected and how you might use them with students. Several **sample sequences of activities** used by Project ASTRO teachers are included in this section.
- Thirteen *Activities* sections labelled A through M, each containing activities about a different area of astronomy. Each activity section contains:
    - a **grade level chart** for the activities in that section
    - an **introduction to teaching** the activities
    - a **background article** on the astronomical topic
    - a reproduction of the **original activity** preceded by a **cover sheet** that briefly describes the activity, discusses its learning goals, provides information about its source, and gives teaching tips and suggestions; and
    - a **resource list** at the end, with books and materials for both adults and students about the topics of the activities in that section
- A *Resources and Bibliographies* section containing resource lists, guides, and articles ranging from the addresses of organizations and suppliers, to astronomy software, to national projects in astronomy education, to a basic library of astronomical books.

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The notebook does not present a sequential curriculum and is not meant to replace existing astronomy textbooks or curriculum guides. Rather, the notebook is a collection of the best astronomy activities we could find from a range of sources, covering a variety of topics and grade levels. We have organized these activities by topic, and have selected activities that have been widely tested in the classroom. Most of the activities are intended for grades 4-9, but many can be easily extended or modified for lower and higher grades. In fact, many of the activities have been used successfully with advanced high school and college students.

We encourage teachers to sequence the activities in ways that meet your students' needs and learning goals. In addition, we have provided several suggested sequences of activities in the *Activity Introduction* of the notebook to help you get started.

You will note that in addition to "pure" astronomy activities, we have included a number of projects and ideas for taking an interdisciplinary approach to teaching astronomy. These activities connect astronomy to social studies, mathematics, writing, art, music, history, and other subjects.

Since the activities come from many different published and unpublished sources, they naturally differ greatly in the amount of background information they include. If you or your students need more explanation or a clearer definition of some of the terms involved in an activity, you can refer to:

- the background article at the front of that activity section
- the recommended resources at the end of that section
- the glossary and articles in the *Astronomy Background* section of the notebook

We have intentionally designed *The Universe at Your Fingertips* in a loose-leaf (three-ring binder) format to allow additional pages and updates to be included at any time. With this in mind, each section of the notebook (including each activity section) is paginated separately, so that we may update one section at a time. After the notebook is published, we anticipate making available update packages containing new activities and resources to keep the materials timely. We also encourage you to take advantage of the notebook's format to re-arrange the sections, to include your favorite articles or activities, to add extensions to activities, and in general to make the whole package as useful in your own teaching as possible. We welcome your suggestions or contributions for consideration for these updates.

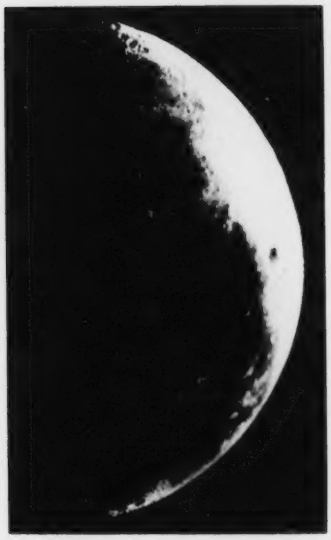
Note also that *The Universe at Your Fingertips* consists of two kinds of materials: those that were created by the Astronomical Society of the Pacific and those that are copyrighted by other publishers. We encourage you (and give you permission) to make copies the ASP's own sheets for colleagues or students. But our agreements with the outside publishers is that you will use the activities they "lent" us only in your own classroom. We and they hope *The Universe at Your Fingertips* will point teachers to full curriculum guides, books, resources and other materials that may not have received wide publicity.

We hope *The Universe at Your Fingertips* will be a useful and often-used resource for teaching astronomy at any grade level. We would be grateful for your comments and suggestions on ways to improve the notebook, and any stories about the ways the notebook has been useful to you. (See feedback form at the end of the notebook.)

SECTION

2

ASTRONOMY BACKGROUND



PLANETS, STARS, AND GALAXIES:

A GRAND TOUR OF THE UNIVERSE

by Andrew Fraknoi &
Sherwood Harrington

Anyone who has ever gazed at the clear night sky from a dark location knows the special fascination of astronomy—the sense of awe and mystery that comes from considering our place in the vastness of the universe.

To the ancients, the planets and stars were simply mysterious lights scattered on the dome of the heavens. Our modern understanding adds the crucial dimension of depth to that simple picture. We now know that some celestial objects are relatively close, while others are unimaginably remote. The twinkling lights of the sky turn out to be other worlds and other suns. Spread among them are vast clouds of gas and dust—reservoirs of raw material to make new stars, new planets, and perhaps even new astronomers. The cosmos is much richer and more complex than the ancients ever dreamed.

Let us, in our mind's eye, take a short tour of the universe as astronomers understand it today, and get acquainted with the main types of objects in the "astronomical zoo."

THE SOLAR SYSTEM

To begin at home, our Earth is a member of the family of planets and moons known as the solar system. Orbiting our star, the Sun, are nine planets and their more than 40 satellites, each a unique world with its own special characteristics. Assorted cosmic debris—in the form of comets, asteroids, and smaller chunks called meteoroids—also share our system with us. (See the glossary later in this notebook if you are not familiar with any of the terms in this article.) Let's examine a few of the planets that are especially noteworthy.

Sunward of us lies the glistening planet Venus, often seen as a brilliant morning or evening star. Perpetually veiled by layers of clouds that include droplets of sulfuric acid, Earth's sister planet hoarded the Sun's heat under its vast cloud layers until surface temperatures stabilized at more than 900 degrees Fahrenheit—hotter than a self-cleaning oven.

Our other planetary neighbor, the red planet Mars turns out to be a cold, "low-pressure" world, with air so thin that if you stepped out on its surface unprotected, your blood would literally boil. On one of the dry, dusty Martian plains, there rises a volcano so enormous that its base would cover the entire state of Nebraska. Nearby there is a "grand canyon" so vast that on Earth it would stretch from Los Angeles to Washington, D.C.

Alien as our neighbor planets sound, the more distant worlds are stranger still. From the perspective of these chilled outer planets, even the coldest and most inhospitable places on Earth begin to seem homey and inviting.

Take Jupiter, the largest of the planets, for example. It is so huge that more than 1,000 Earths would fit into its vast sphere. Yet if you tried to land on Jupiter, you couldn't—you would simply

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sink in and in and in. Like the other outer planets, Jupiter is composed mainly of gas and liquid, with perhaps a small solid core at its center. Yet this enormous planet spins on its axis in only 10 hours (less than half the spin-rate of our much smaller Earth), setting up vast continent-sized storm systems in its outer layers that can persist for centuries. We see one of these storms as Jupiter's Great Red Spot, which is sometimes as large as three Earths laid side by side.

Surrounding Jupiter are at least 16 moons and a thin ring—a family so varied and complex, astronomers like to say that the giant planet is the center of a mini-solar system of its own. Four of Jupiter's moons are so large that if they orbited the Sun, we would respectfully call them planets and make students memorize their names. One of these satellites, Io, turns out to be the most volcanically active body in the solar system—we saw the moon literally "churning itself inside out" as the Voyager spacecraft flew by.

Just a little smaller than Jupiter, but still much bigger than the Earth, Saturn is distinguished by a large and complex ring system. Saturn is not unique in having rings—we now know that Jupiter, Uranus, and Neptune have them as well—but its system of rings and ringlets is so huge that it would almost fill the space between our Earth and its Moon. These rings, by the way, are not solid, but consist of billions of icy pieces following a well-organized traffic pattern around Saturn's equator.

The centerpiece of our planetary system is the Sun, a million-mile-wide, yellowish star whose vast outpouring of energy illuminates all the worlds around it and sustains the fragile life-forms on the watery planet we call Earth.

To give you some sense of the scale of our home system, consider the following analogy:

If the Sun were reduced to the size of a basketball, the Earth would be an apple-seed some 30 yards from the ball. Jupiter would be a golf ball 150 yards away, and tiny Pluto, which is usually (but not always) the outermost planet, would be a dust mote almost three-quarters of a mile from the center. And that is just our immediate neighborhood in the cosmos!

IN THE MILKY WAY GALAXY

Beyond the solar system, there is a vast expanse of space, with an occasional grain of dust or elemental atom floating in the dark emptiness. The nearest other star system—known as Alpha Centauri and best seen from the Earth's southern latitudes—is so far away that Voyager, the fastest spacecraft our species has built, would take about 100,000 years to reach it. Even beams of light, which travel at a phenomenal 670 million miles an hour, take a little over four years to make the journey between these two systems.

Light is the fastest traveler we know of in the universe, so astronomers use its pace to denote distances. Thus we say Alpha Centauri is a little over four *light years* away—about 25 thousand billion miles.[1] Since we cannot know about new developments concerning this star until its light actually reaches us, this means that when a stargazer sees Alpha Centauri, he or she is seeing it as it was approximately four years ago.

Other stars are even farther than Alpha Centauri, separated from us by increasingly larger gulfs of space and time. (The farther we look into the cosmos, the longer ago the light we see must have left on its journey to us.) If we could visit them, many stars would look smaller and dimmer than the Sun while others would be much brighter and larger. The reason they all look like little points of light is that they are so enormously far away.

One of the most profound discoveries of modern astronomy is that stars do not last forever. Over the millions and billions of years, stars are born from the raw material of space, shine steadily for some 90% of their lives, swell up briefly, and eventually die when they run out of the central fuel that keeps them hot. Luckily new generations of stars keep forming all the time, maintaining a rich variety in our skies.

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[1] It may seem odd to use "years"—a unit of time—to describe a distance. But we do this in everyday usage too, when we say that a shopping center is 20 minutes away.

All the stars visible with the naked eye, and many others, make up a huge spiral-shaped grouping called the Milky Way Galaxy. Being inside the dusty Milky Way Galaxy makes it hard for us to get a good picture of it—akin to trying to make sense of yourself from inside your kidneys. Our best current estimate in that the Galaxy comprises some 100 billion to 400 billion suns and a vast amount of raw material (atoms, molecules and dust).

By the way, our theories predict that planets should be a natural byproduct of making stars and therefore should be plentiful in our Galaxy. But unfortunately, planets are much much fainter than stars, and very difficult to see. Even with our large telescopes on Earth and in space, we do not have any conclusive proof that planets outside our solar system exist. (There is some recent evidence for a planet around a stellar corpse called a pulsar, but such a planet may be the product of the explosive death of a star, instead of having accompanied the star from birth.) Still, several programs to detect planets with modern instruments and sophisticated techniques are now under way. We just have to "stay tuned" to new developments in this exciting field.

One of the most interesting and humbling discoveries of 20th century astronomy was the realization that the Sun resides in the "boondocks" of the Milky Way Galaxy, some 30,000 light years from its center. We don't even have a place on one of the main spiral arms of stars that define our galaxy's structure; instead, we are off on a small local "spur" of stars. The entire Galactic spiral disk is at least 100,000 light years across and may be surrounded by a much larger "halo" of dark material whose nature astronomers do not yet understand.

BEYOND THE MILKY WAY

Beyond our own Galaxy lie even larger and emptier regions of what we call "intergalactic space." These areas are so unpopulated that on average you might run across only a single atom in every cubic yard of space. Accompanying our Milky Way are two or three small "satellite" galaxies, called the Magellanic Clouds. They are 150,000 to 200,000 light years away and give astronomers (in the Southern Hemisphere, where the clouds are visible) an excellent opportunity to study another system of stars that has evolved more or less separately from our own.

The nearest major galaxy, barely visible to the naked eye on dark nights in the constellation of Andromeda, is so well known among astronomy buffs it is often just called the Andromeda Galaxy. A beautiful spiral grouping very much like our own, this galactic neighbor is about 2 million light years away. Thus, the light we see from it tonight left this galaxy 2 million years ago, when our species was just beginning to establish its foothold on our planet.

Beyond Andromeda, our telescopes have revealed billions of other galaxies—myriad islands of stars dotting the cosmic ocean. Some of these systems strongly resemble our own, but others are strangely different. Many seem darker and "used up," with far fewer young stars than our Milky Way. Others seem to be the results of "mergers"—where the collision of two or more galaxies has produced a complex new system. Some are seen to be torn by violence—huge "engines" at their centers seem to be spewing out energetic "jets" of high-speed material that sometimes distort the shape of their galaxy.

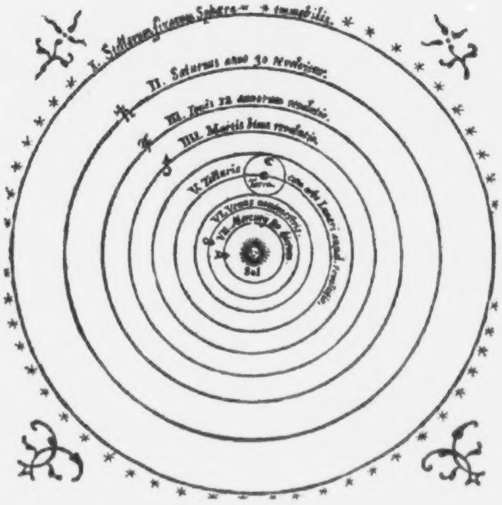
The most energetic of these "active" galaxies are called *quasars* by astronomers, a contraction from their original name "quasi-stellar objects." From far away, only the central pinpoint of violence can be clearly distinguished, and so the objects looked "quasi-stellar" (like a star) when first discovered. Most quasars are many billions of light years away and we thus see them as they were many billions of years ago. Astronomers suspect that they represent an earlier, more violent phase in the evolution of galaxies and the universe.

Galaxies and quasars stretch away from us in all directions, the number of known systems increasing as our telescopes become more powerful. Like the stars, they too are organized into systems—groups or clusters of galaxies that share a common motion.

THE LARGEST OF SCALES

Very recently, astronomers have discovered that even these grand groups of galaxies are not randomly distributed. Galaxy groups seem strung out in vast rounded filaments, separated by enormous voids with relatively few galaxies. This structure, which we are just beginning to glimpse, may hold important clues to the unimaginably violent processes that created the universe.

Attesting to that primeval violence is the expansion of the universe itself. Astronomers can measure that galaxy groups are moving away from each other in a grand pattern we call the expanding universe. According to our best understanding, the galaxies seem to move apart because space itself is expanding in all directions. The explosive beginning of that expansion - some 12 to 20 billion years ago is called by astronomers "the big bang." Understanding more about the big bang, the expansion of the universe, and its ultimate fate; tracing how the evolution of the universe made humanity possible; and exploring whether this vast cosmos might contain other examples of intelligent life; all these are the greatest questions astronomers will be trying to answer in the decades to come.



HOW FAST ARE YOU MOVING WHEN YOU ARE SITTING STILL?

by Andrew Fraknoi
Astronomical Society of the Pacific

When, after a long day of running around, you finally find the time to relax in your favorite armchair, nothing seems easier than just sitting still. But have you ever considered how fast you are really moving when it seems that you are not moving at all?

When we are on a smoothly riding train we sometimes get the illusion that the train is standing still and the trees are moving backwards. In the same way, because we ride with the spinning Earth, it appears to us that the Sun and the stars are moving as day and night alternate. Actually it is our planet that turns on its axis once each day—and all of us on the Earth's surface are turning with it. To make one complete rotation in 24 hours, a point near the equator of the Earth, for example, must move at close to 1000 miles per hour. Because gravity holds us to the Earth, we (and all other things on its surface) move with the planet and don't especially notice its rotation.

In addition to spinning on its axis, the Earth also revolves around the star which we call the Sun. We are approximately 93 million miles away from the Sun and at this distance it takes us one year to go completely around. The full path of the Earth's orbit is close to 600 million miles; to go around this immense circle in a mere 365 days requires an average speed of 66,000 miles per hour. That's speed not even the drivers at the Indianapolis 500 ever dream of!

Now our Sun is just one star among several hundred billion others which make up the spiral-shaped aggregation we call our Milky Way Galaxy. Within this immense group, each star is itself moving; any planet orbiting a star will share its motion through space with it.

If we want to describe the motion of a star like our Sun among the other stars, we run up against a problem. We usually define motion by comparing the moving object to something at rest. A car moves at 60 m.p.h. relative to the highway sign or lamp-post which is fixed in the ground. But if all the stars in the Galaxy are moving (both in random and in organized ways), what shall be the reference post to which we can compare our Sun's motion?

Astronomers define a *local standard of rest* in our section of the Galaxy by the average motion of all the stars in our neighborhood. (In using common words like "local" and "neighborhood," it is important to keep in mind that even the nearest star is about 25 thousand billion miles away!)

Relative to this local standard, our Sun (and with it, the Earth) are moving at about 43,000 miles per hour toward the bright star Vega in the constellation of Lyra. This speed, though it seems outrageous to us, is not at all unusual for stars.

In addition to the individual motions of the stars within it, the entire Galaxy spins on its axis like an enormous pinwheel. Although the details of the motion are complicated, our measurements show that any star at the distance of our Sun from the center of the Galaxy takes about 240 million years to make one complete revolution. (Some astronomers call this our "galactic year".)

You might think that with so much time for a single orbit, the Sun's motion around the Galaxy would be quite slow. But actually, the Galaxy is so huge that to make it around in 240 million years, our Sun must travel at approximately 500,000 miles per hour. And the Earth, anchored to the Sun by its gravitational pull, follows along at the same incredible speed.

WHAT ASTRONOMERS DO

By Andrew Fraknoi
Astronomical Society of the Pacific

When you read about an astronomer in your local newspaper, what is the image that comes to your mind? (Before you read on, try this for yourself — close your eyes and picture an astronomer.)

For many people, the picture is a middle-aged man, dressed in warm clothing, in an open dome on a lonely mountaintop, peering intently into the eyepiece of a large telescope, searching for a faint glimmer of light from a distant star. Like so many stereotypes, this one isn't very close to the way things are today.

First of all, more and more astronomers these days are women. While women have made major contributions to the exploration of the universe for centuries, today it has become less and less unusual to find a woman as the director of a major project or observatory, as the featured speaker at a meeting, or as the president of a scientific society.

Furthermore, very little astronomy is done by looking directly through a large telescope. Rather than letting the faint shafts of light from planets, stars, gas clouds, or galaxies fall temporarily on an unreliable human eye, it is much more efficient to record the light on photographic film or on electronic detectors similar to those found in high-quality video cameras. The astronomer may look through a smaller telescope to make sure the large instrument stays pointed correctly; but with the advent of computer-controlled pointing and video display units at the larger observatories, even this task can be carried out from another room. Thus warm clothing may no longer be necessary in some places, and astronomers no longer need 20/20 vision.

But perhaps the most important way in which reality differs from the stereotype is that there are many astronomers today who do not use a light-gathering telescope in their work at all. An ever-growing group employs dish-shaped antennas for searching for natural radio signals from cosmic objects. Many fascinating celestial phenomena, from exploding galaxies to the magnetic field of the giant planet Jupiter, can best be explored by means of the radio signals they emit.

Similarly, there are astronomers who place electronic "thermometers" at the end of their telescopes to look for infrared (or heat) rays from the stars. Because the Earth's atmosphere filters out many of the infrared rays, these astronomers can be found on the world's highest peaks (such as the 14,000-foot summit of the Mauna Kea volcano in Hawaii) or in jet aircraft 50,000 feet above the ground.

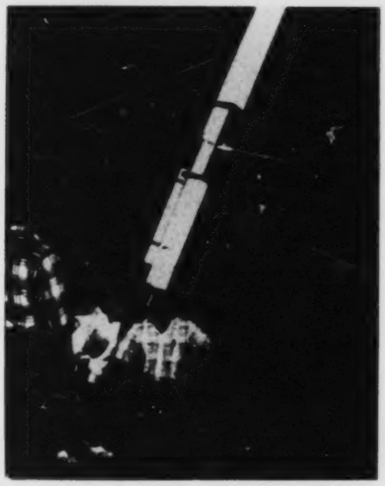
Another group pursues the even more difficult task of detecting high-energy radiation (such as X-rays and gamma rays) from space. These waves do not make it through our atmosphere at all and can only be observed by instruments flown on satellites launched by NASA (and similar organizations in other countries).

And a large fraction of modern astronomers never use telescopes at all. These are the theoretical astronomers (or astrophysicists) whose instruments are paper, pencil, or a modern computer, and whose calculations and theories form the groundwork for the planning and interpretation of the observations other astronomers make.

And we should not forget that many astronomers spend a good part of their time teaching and writing. In planetaria, and colleges and universities across the country, many hundreds of talented individuals devote their time to making the often complex results of modern astronomical research comprehensible to students and the public.

There is also one way in which astronomy differs from almost all other sciences. Assisting the approximately 5,000 professional astronomers in the U.S., is a large group of amateur astronomers—people in all walks of life for whom astronomy is a hobby and passion. There are still a number of areas where such amateurs can make significant contributions to science—discovering new comets or exploding stars, monitoring weather patterns on the planets, or following the behavior of stars that change their brightness in unexpected ways. Many of these amateurs share their fascination with and knowledge of the universe through school visits, evening "star parties", or an annual "Astronomy Day" in the spring.

While their work may differ, there is one common belief which all these astronomers probably share. I think they would agree that their field, while it may not be immediately "relevant" to everyday life, affords us a much broader perspective and deeper view of who we are, where we came from, and where we are going in this awesome immensity we call the universe.



GETTING STARTED IN ASTRONOMY

by Alan M. MacRobert
Sky & Telescope Magazine

"Dear Sky & Telescope," the letter began. "I am 20 years old and new to astronomy. I have always been fascinated with the stars and universe. What would you suggest my first step be to get into the hobby, so that I might get the most enjoyment out of it?"

It's a good question, one that deserves better answers than most beginners find. Many newcomers to astronomy write or call us in exasperation after blundering down some wrong trail that leaves them lost and frustrated. Such experiences, widely shared, create a general public impression that astronomy is a tough hobby to get into. But this impression is altogether wrong and unnecessary.

Many other hobbies that have magazines, conventions, and vigorous club scenes have developed effective ways to welcome and orient beginners. Why can't we? For starters, novice astronomers would have more success if a few simple, well-chosen direction signs were posted for them at the beginning of the trail.

What advice would help beginners the most? *Sky & Telescope* editors brainstormed this question. Pooling thoughts from nearly 100 years of collective experience answering the phone and mail, we came up with a number of pointers to help newcomers past the pitfalls and onto the straightest route to success. We present them either for your own use or to remember whenever someone asks, "Where do I start in astronomy?"

1) RANSACK YOUR PUBLIC LIBRARY

Astronomy is a learning hobby. Its joys come from intellectual discovery and knowledge of the cryptic night sky. But unless you live near an especially large and active astronomy club, you have to make these discoveries and gain this knowledge by yourself. In other words, you need to become self-taught.

The public library is the beginner's most important astronomical tool. Maybe you found *Sky & Telescope* there. Comb through the astronomy shelf for beginner's guides. Look for aids to learning the stars you see in the evening sky. One of the best is the sky map in the center of *Sky & Telescope* magazine. When a topic interests you, follow it up in further books.

Many people's first impulse, judging from the phone calls, is to look for someone else to handle their education—an evening course offering, a planetarium, or some other third party. These can be stimulating and helpful. But rarely do they present what you need to know right now. Self-education is something you do yourself, with books, using the library.

2) LEARN THE SKY WITH THE NAKED EYE

Astronomy is an outdoor nature hobby. Go into the night and learn the starry names and patterns overhead. *Sky & Telescope* will always have its big, round all-sky map for evening star-finding. Other books and materials will fill in the lore and mythology of the constellations the map shows, and how the stars change through the night and

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the seasons. Even if you go no further, the ability to look up and say "There's Arcturus!" will provide pleasure, and perhaps a sense of place in the cosmos, for the rest of your life.

3) DON'T RUSH TO BUY A TELESCOPE

Many hobbies require a big cash outlay up front. You can't surf without a surfboard. But astronomy, being a learning hobby, has no such entrance fee. Conversely, paying a fee will not buy your way in.

Thinking otherwise is the most common beginner's mistake. Half the people who call for help ask, "How do I see anything with this %@&*# telescope?!" They assumed that making a big purchase was the essential first step.

It doesn't work that way. To put a telescope to rewarding use, you first need to know the sky as seen with the naked eye, be able to find things among the stars with sky charts, know something of what a telescope will and will not do, and know enough about the objects you're seeking to recognize and appreciate them.

The most successful, lifelong amateur astronomers are often the very ones who began with the least equipment. What they lacked in gear they had to make up for in study, sky knowledge, map use, and fine-tuning their observing eyes. These skills stood them in good stead when the gear came later.

4) START WITH BINOCULARS

A pair of binoculars is the ideal "first telescope" for several reasons. Binoculars show you a wide field, making it easy to find your way around; a higher-power telescope magnifies only a tiny, hard-to-locate spot of sky. Binoculars give you a view that's right-side up and straight in front of you, making it easy to see where you're pointing. An astronomical telescope's view is upside down, sometimes mirror-imaged, and usually presented at right angles to the line of sight.

Binoculars are also fairly inexpensive, widely available, and a breeze to carry and store. And their performance is surprisingly respectable. Ordinary 7- to 10-power binoculars improve on the naked-eye view about as much as a good amateur telescope improves on the binoculars. In other words, they get you halfway there for something like a tenth to a quarter of the price—an excellent cost-benefit ratio.

For astronomy, the larger the front lenses are the better. High optical quality is important too. But *any* binocular that's already knocking around the back of your closet is enough to launch an amateur-astronomy career.

5) GET SERIOUS ABOUT MAPS AND GUIDEBOOKS

Once you have the binoculars, what do you do with them? You can have fun looking at the Moon and sweeping the star fields of the Milky Way, but that will wear thin pretty fast. However, if you've learned the constellations and obtained detailed sky maps, binoculars can keep you busy for a lifetime.

They'll reveal most of the 110 "M objects," the star clusters, galaxies, and nebulae that were first cataloged by Charles Messier in the late 18th century. Binoculars will show the ever-changing positions of Jupiter's satellites and the crescent phase of Venus. On the Moon you can learn to recognize dozens of craters, plains, and mountain ranges by name. You can split scores of colorful double stars and spend years following the fadings and brightenings of variables. *If* you know what to look for.

A sailor of the seas needs top-notch charts, and so does a sailor of the stars. Fine maps bring the fascination of hunting out faint secrets in hidden sky realms. Many reference books describe what's to be hunted and the nature of the objects you find. Moreover, the skills you'll develop using maps and reference books with binoculars are exactly the skills you'll need to put a telescope to good use.

6) FIND OTHER AMATEURS

Self-education is fine as far as it goes, but there's nothing like sharing an interest with others. Over 400 astronomy clubs in North America are listed in the center of last September's *Sky & Telescope* (A reprint of the listing is available for $2.00.) Call the clubs near you. Maybe you'll get invited to monthly meetings or nighttime star parties and make a lot of new friends. Clubs range from tiny to huge, from moribund to vital. But none would have published a phone number unless they hoped you would call.

Computer networks offer another way to contact other amateurs. CompuServe, GEnie, America Online, and the Internet all have active astronomy areas. These present a constant flow of interesting news and chatter by amateurs who are quick to offer help, opinions, and advice. Many independent bulletin boards specialize in astronomy too.

7) WHEN IT'S TIME FOR A TELESCOPE, PLUNGE IN DEEP

Eventually you'll know you're ready. You'll have spent hours poring over the ads. You'll know the different kinds of telescopes, what you can expect of them, and what you'll do with the one you pick.

This is no time to scrimp on quality; shun the flimsy, semi-toy "department store" scopes that may have caught your eye. The telescope you want has two essentials. One is a solid, steady, smoothly working mount. The other is high- quality optics—"diffraction-limited" or better. You may also want large aperture (size), but don't forget portability and convenience. The telescope should not be so heavy that you can't tote it outdoors, set it up, and take it down reasonably easily. The old saying is true: "The best telescope for you is the one you'll use the most."

Can't afford it? Save up until you can. Another year of using binoculars while building a savings account will be time you'll never regret. It's foolish to blow half-accumulated telescope money on something second-rate that will disappoint. (You can read more about choosing a first telescope in the December 1993 issue of *Sky & Telescope.*) Or consider building the scope yourself, an activity that many clubs support.

8) LOSE YOUR EGO

Astronomy teaches patience and humility—and you'd better be prepared to learn them. There's nothing you can do about the clouds blocking your view, the extreme distance and faintness of the objects you desire most, or the timing of the long-anticipated event for which you got all set up one minute late. The universe will not bend to your wishes; you must take it on its own terms.

Most objects within reach of any telescope, no matter how large or small it is, are *barely* within reach. Most of the time you'll be hunting for things that appear very dim, small, or both. If flashy visuals are what you're after, go watch TV.

"Worthiness" is the term entering the amateur language for the humble perseverance that brings the rewards in this hobby. The term was coined by Ken Fulton, author of *The Light-Hearted Astronomer* (1984)—a book describing the hobby as a jungle full of snares, quicksand, and wild beasts that only those with the spiritual skills of a martial artist can traverse unmauled. It's really not that bad—but there are definitely times when a Zen calmness will help you through.

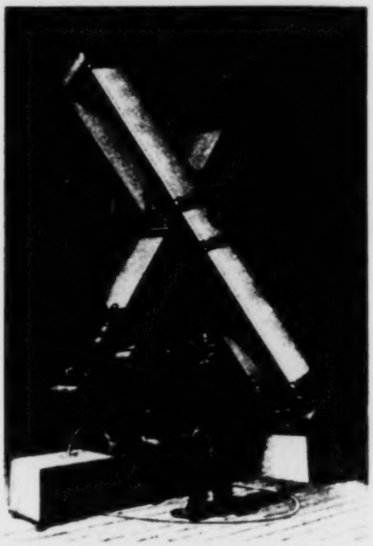
9) RELAX AND HAVE FUN

Part of losing your ego is not getting upset at your telescope because it's less than perfect. Perfection doesn't exist, no matter what you paid. Don't be compulsive about cleaning lenses and mirrors or the organization of your observing notebook.

And don't feel compelled to do "useful work" right away. Ultimately, some of the most rewarding branches of amateur astronomy involve scientific data collecting—venturing into the nightly wilderness to bring home a few bits of data that will advance humanity's knowledge of the universe in some tiny but real way. Such a project often marks the transformation from "beginner" to "advanced amateur," from casual sightseer to cosmic fanatic. But it only works for some people, and only when they're good and ready.

Amateur astronomy should be calming and fun. If you find yourself getting wound up over your eyepiece's aberrations or Pluto's invisibility, take a deep breath and remember that you're doing this because you enjoy it. Take it as fast or as slow, as intense or as easy, as is right for you.

Alan MacRobert *is Associate Editor of Sky & Telescope magazine. Sky & Telescope—"The Essential Magazine of Astronomy"—is published monthly by Sky Publishing Corp., P. O. Box 9111, Belmont, MA 02178. One-year subscription is $27.00 for the United States and possessions, $36.38 for Canada, $42.00 airmail to Europe, and $34.00 all other international. Subscription discounts are available for astronomy clubs. For subscription information or to receive a free color catalog of astronomy-related products, call 800-253-0245, 617-864-7360, or fax 617-864-6117.*



A BRIEF GLOSSARY OF COMMONLY USED ASTRONOMICAL TERMS

by Sherwood Harrington and Andrew Fraknoi

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Astronomical Society of the Pacific
390 Ashton Ave.,
San Francisco, CA 94112

Asteroid: Any of the thousands of small rocky objects that orbit around the Sun, most of them between the orbits of Mars and Jupiter (although some pass closer to the Sun than Earth does and others have orbits that take them well beyond Jupiter.) The largest asteroid is one called Ceres; it's about as wide as the state of Texas.

Astronomical Unit: A unit of distance equal to the average spacing between the Earth and the Sun. Usually abbreviated "A.U.," it is equal to about 150 million kilometers (93 million miles), and is a distance that light takes about eight minutes to cover. It is a handy size to use for expressing distances in the Solar System. (For example, the diameter of the orbit of the most distant planet, Pluto, is about 80 A.U.)

Big Bang: The primeval explosion of space, time, matter and energy that most astronomers think gave rise to the Universe as we see it today.

Binary Star: A system of two stars, orbiting around one another. Binary (and triple and even higher multiples) stars are very common; astronomers estimate that about half of all stars are members of multiple-star systems. The nearest "star" to our solar system, Alpha Centauri, is actually our nearest example of a multiple star system — it consists of three stars.

Black Hole: An object whose gravitational pull is so strong that — within a certain distance of it — nothing can escape, not even light. Black holes are thought to result from the collapse of certain very massive stars at the ends of their lives. "Supermassive black holes" — with masses millions of times the Sun's — may form in the crowded cores of large galaxies.

Comet: A small chunk of ice and dust, (only a few miles across) which, when it comes close enough to the Sun, can develop a tenuous "tail." Tails of comets are made of gas and dust that have been driven off the comet's surface by the Sun's radiation or wind of particles and they always point away from the Sun (no matter what direction the comet is moving). Comets spend most of their time very far from the Sun; a few become active for a short period (a few months at most) as they move quickly around the Sun on elongated orbits.

Constellation: 1. [older meaning] A pattern of stars on the sky, named for a person, animal, or object (usually from mythology). Astronomers use constellations to designate directions in space; for example the Great Galaxy "in Andromeda" lies in the direction from us marked by the pattern of stars we call Andromeda (the Princess of Ethiopia in Greek mythology). Just as patterns we see in the clouds are not permanent, neither are the star patterns of constellations, since the stars move (albeit very slowly on the timescale of a human lifetime). The constellations of 100,000 years ago were quite different from today's. **2.** [modern meaning] One of 88 sectors into which astronomers divide the sphere of the sky, each named after a traditional constellation in that sector.

Cosmology: The branch of astronomy that deals with the origin, large-scale properties, and the evolution of the observable universe.

Dark Matter: Matter that is detected by its gravitational influence, but not by any radiation it gives off. Evidence is accumulating that a substantial fraction of the universe may be made of dark matter.

Eclipse: The blocking of all or part of the light from one object by another. For example, a "lunar eclipse" occurs when the Earth's shadow falls on the Moon, preventing sunlight from illuminating all of its surface. A "solar eclipse" occurs when the Moon passes directly between us and the Sun, blocking part or all of the Sun's light from reaching us.

Electromagnetic Radiation: Waves of energy produced by changing electric and magnetic fields. This energy travels through space at the speed of light. Includes radio waves, infrared, light, ultraviolet, x-rays, and gamma rays.

Equinox: Either of the two instants during the year when the Sun is directly over the Earth's equator. In the Northern Hemishpere, the Spring Equinox occurs around March 21st, and the Fall Equinox happens around September 21st (although the specific dates vary slightly from year to year). At the time of the equinoxes, the length of day and night are very nearly equal all over the world. Spring and Fall officially begin at the instants of the Vernal and Autumnal Equinoxes, respectively.

Escape Velocity: The speed you need to break away from the gravitational pull of another body. The Earth's escape velocity is about 40,000 km/hr.

Galaxy: A large assemblage of stars (and often gas and dust), typically containing millions to hundreds of billions of member stars. A galaxy is held together by the gravitational attraction of all its member stars (and other material) on one another. The visible parts of most galaxies are either of a flattened, spiral form or a fatter ellipsoidal shape without a spiral pattern. The "Milky Way Galaxy," of which our Sun is a part, is a spiral galaxy with a disk about 100,000 light years across containing roughly 400 billion stars. Our Sun is in the disk of the spiral, about 2/3 of the way out from the center.

Globular Cluster: A large congregation of stars (containing hundreds of thousands to about a million stars) which is spherical in form. Over a hundred globular clusters are members of our Milky Way Galaxy, distributed in a round halo around the Galaxy's disk. Globular clusters, which can also be detected in other galaxies, are mostly made up of very old stars.

Light Year: The distance light travels in one year in a vacuum. Light travels at a speed of about 300,000 kilometers per second (186,000 miles per second) in a vacuum. A light year is about nine and a half trillion kilometers (6 trillion miles) long.

Local Group: The relatively small cluster of galaxies of which our Milky Way is a part. It is known to contain several dozen member galaxies, but most of those are "dwarf" galaxies, considerably smaller than our own. The Local Group is about three million light years across, and is itself part of a "supercluster" of clusters of galaxies which is centered on a huge aggregate called "The Virgo Cluster."

Magnitude: A way of expressing the brightnesses of astronomical objects inherited from the Greeks. In the magnitude system, a lower number indicates a brighter object (for example, a 1st magnitude star is brighter than a 3rd magnitude star). Each step in magnitude corresponds to a brightnesss difference of a factor of about 2.5. Stars of the 6th magnitude are the faintest the unaided human eye can see.

Magellanic Clouds: The two closest galaxies to us which are satellites of our own Milky Way. They are each irregular in form and relatively small. They are about 160,000 light years away from our Galaxy in a direction such that they can be seen easily only from Earth's Southern Hemisphere. The first Europeans to record their existence were Ferdinand Magellan's crew in the early 1500's; to them, the two galaxies looked like small clouds separated from the Milky Way.

Meteor: A bit of solid debris from space, burning up in Earth's atmosphere due to friction with the air. (The luminous streaks they trace across the sky are commonly called "shooting stars," although they have nothing to do with stars!) Before entering Earth's atmosphere (with a typical speed of about 25,000 mph) the body is called a "meteoroid." If any of the object survives its fiery passage down through the air, then those parts which hit the ground are called "meteorites."

Milky Way: A faint band of hazy light that can be seen from clear, dark locations and which stretches all the way around the sky. With binoculars or a small telescope, it can be seen to be composed of vast numbers of individual, faint stars. It is actually the disk of our own Galaxy — seen from our perspective (within the disk), the flat lens-shape of the Galaxy appears to surround us. Astronomers often use the term "Milky Way" to refer to our entire Galaxy, rather than to just its appearance in our sky. [See "Galaxy."]

Nebula: A cloud of gas and/or dust in interstellar space. (The word "nebula" in Latin means "cloud"; its plural is "nebulae.") Nebulae can make themselves apparent by glowing (as "emission nebulae"), by scattering light from stars within them (as "reflection nebulae"), or by blocking light from things behind them (as "obscuration nebulae").

Neutron Star: A crushed remnant left over when a very massive star explodes. Made almost entirely of neutrons (subatomic particles with no electric charge), these stellar corpses can pack about twice as much mass as there is in the Sun into a sphere only about ten kilometers across. A teaspoonful of their material would weigh more than all the automobiles in the US put together. Some neutron stars are known to spin very rapidly, at least at the beginning, and can be detected as "pulsars": rapidly flashing sources of radio radiation or visible light. The pulses are produced by the spinning of the neutron star, much like a spinning lighthouse beacon appears to flash on and off.

Nova: A star that abruptly and temporarily increases its brightness by a factor of hundreds of thousands. Unlike supernovae (much more violent explosions which can destroy the stars that produce them), stars that "go nova" can do so more than once. Novae are thought to occur in binary stars in which one member is a compressed dwarf star (such as a white dwarf or a neutron star) orbiting close to a much larger star. According to this theory, material from the larger star's outer layers accumulates on the dwarf's surface, becoming ever hotter and more compressed by the dwarf's strong gravity, until the "stolen" material explodes. [See "supernovae," "binary star," "white dwarf," and "neutron star."]

Observatory: A place where telescopes are kept. Major astronomical observatories with telescopes that observe visible light are now placed primarily on remote mountain tops to escape the bright light of cities and to take advantage of the steady and clear viewing that high altitudes generally afford. Most "radio observatories" need not be located at high altitudes, though, since most of the radio waves that can be studied from Earth make it all the way through our atmosphere easily. For some kinds of radiation that do not make it through our atmosphere, observatories must be located in space. [See "telescope," "radio astronomy."]

Orbit: The path of one body around another (such as the Moon around the Earth) or around the center of gravity of a number of objects (such as the Sun's 200-million-light-year path around the center of the galaxy).

Parsec: A unit of distance equal to about 3.26 light years (or, more precisely, equal to 206,265 Astronomical Units). Technically, a parsec is defined to be the distance from which the Earth and Sun would appear to be separated from one another by one second of arc (about the size a dime would appear to be if seen from a distance of two miles).

Phases of the Moon: The changing appearance of the Moon as it orbits around the Earth. At "New Moon," the Moon is on the same side of the Earth as the Sun is, and we see only the part of the Moon which is in shadow (another term for New Moon is the "dark of the Moon"). A quarter of an orbit later (about a week after New Moon), we see the Moon illuminated by sunlight from the side. Thus one-half of the disk of the Moon which faces us is in sunlight — the right side as seen from Earth's northern hemisphere: this phase is called "First Quarter." About two weeks after New Moon, our satellite has traveled around to the other side of its orbit, and the side facing us also faces the Sun and is fully illuminated as we see it; that phase is called "Full Moon." Three-quarters of a lunar orbit after New Moon, at "Last Quarter," the Moon is again illuminated from the side (the left side as seen from the Northern Hemisphere). About a week after that, the Moon is New again, and the cycle starts over. Between First Quarter and Last Quarter, when more than half of the side of the Moon facing us in sunlight, the Moon is said to be "Gibbous." From Last Quarter to First Quarter, when more than half of the side of the Moon facing us is in shadow, the Moon is said to be a "Crescent."

Planet: A major object which orbits around a star. In our solar system, there are nine such objects which are traditionally called "planets": Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. (There are no "official" specifications for how big an object must be to be called a planet rather than, for example, an "asteroid.") While no individual planet has ever been seen orbiting around another star, we wouldn't expect to see them, given the limits of current technology. It is suspected, though, that planets are common companions of stars.

Planetarium: A domed theater in which a special device in the center of the room projects a simulation of the nighttime sky onto a dome above the audience. Planetaria generally can show how the nighttime sky looks from anywhere on the Earth's surface at any time (for thousands of years into the past and future).

Pulsar: See "Neutron Star."

Quasar: One of a class of very distant (typically billions of light years away), extremely bright, and very small objects. The term "quasar" means "quasi-star" — that is, something that looks like a star but can't actually be a star. A typical quasar produces more light each second than an entire galaxy of stars does, and it does so from a region of space which is perhaps as small as our Solar System. Precisely how they produce their prodigious amounts of energy is not known, but astronomers suspect that their brilliance may be connected with the violent effects of very massive black holes at the centers of distant, dim galaxies on material right around them. [See "Black Hole."]

Radio Astronomy: The study of naturally occurring radio waves from objects in the universe. Radio and visible-light waves are the only kind of electromagnetic radiation which can reach the ground easily from space. Partly because of this, radio astronomy became the first non-visible branch of astronomy to be actively developed.

Red Giant: A very large, distended, and relatively cool star which is in the final stages of its life. A typical red giant, if placed where the

Sun is in our solar system, might extend past the orbit of Mars. The relatively cool temperature of its outer layers (perhaps only 2,000 degrees Centigrade as compared to the Sun's 6,000 degrees) would make it look orange or red instead of yellowish-white. (The Sun is predicted to become a Red Giant about five billion years from now.)

Red Shift: The lengthening (or "stretching") of light waves coming from a source moving away from us. It is called a red shift because the waves are shifted toward the long or red end of the spectrum. (If a source of light is moving toward us, the opposite effect — called a "blue shift" — takes place.) Light from all galaxies outside the Local Group is "redshifted," indicating that they are moving away from us (and from each other). This phenomenon is called the "expansion of the Universe."

Resolution: The ability of an instrument to make out fine detail (or separate two objects that are close in the sky), expressed in terms of an angle on the sky. [See "Second of Arc."]

Second of Arc: A very small angle which is equal to 1/60th of a minute arc (which, in turn, is 1/60th of a degree). A line on the sky from horizon to horizon extends 180 degrees. A U.S. 10-cent piece seen from a distance of two miles has an apparent diameter of about a second of arc.

S.E.T.I.: An abbreviation for the "Search for Extra-Terrestrial Intelligence." At present, astronomers are undertaking this search by trying to find radio waves from space which may be artificial (i.e., intelligently coded).

Satellite: An object orbiting around another, larger one. For example, smaller bodies orbiting around planets are called those planets' "satellites" (or, occasionally, "moons"). Probes we launch into orbit around the Earth are called "artificial satellites."

Solar System: The Sun and all things orbiting around it, including the nine major planets, their satellites, and all the smaller pieces such as asteroids and comets.

Solstice: Either of the two instants during the year when the Sun as seen from Earth is farthest north or south of the equator. The Summer Solstice (when the Sun is directly over the Tropic of Cancer) occurs around June 21st; the Winter Solstice (when the Sun is over the Tropic of Capricorn) happens around December 21st. In the Northern Hemisphere, summer and winter officially begin at the instants of the Summer and Winter Solstices, respectively.

Spectrum: The band of colors, from violet through red, obtained by passing white light through a prism (or another device that spreads light out into its component colors). Each element in the atmosphere of a star or planet absorbs light at specific colors, unique to that element. Astronomical "spectroscopy," the study of the spectra of astronomical objects, is a very powerful tool in determining the composition, temperature, pressure and other characteristics of celestial objects.

Star: A large hot ball of gas which generates energy in its core by nuclear reactions. (The Sun is our local example of a star.)

Star Cluster: A group of stars which are held together by their mutual gravitational attraction. In the Milky Way, there are two different kinds of star clusters: ones called "open" (or "galactic") star clusters which are generally sparsely populated and exist only in the disk of the Galaxy, and the larger, older "globular" clusters. [See "Globular Cluster."]

Sun: The star at the center of our solar system.

Supernova: An explosion which marks the end of a very massive star's life. When it occurs, the exploding star can outshine all of the other stars in the galaxy in total for several days and may leave behind only a crushed core (perhaps a neutron star or black hole). While most supernovae in our Galaxy are probably hidden from our view by interstellar gas and dust, astronomers can detect supernova explosions in other galaxies relatively frequently.

Telescope: An instrument designed to gather light (or other kinds of radiation) and bring it to a focus, where the radiation can be analyzed. The primary purpose of most astronomical telescopes is to provide the brightest possible images, since most things that astronomers study are very faint. Thus, the "size" associated with a telescope (such as the "200-inch" on Palomar Mountain) refers to the diameter of its light-gathering lens or mirror.

Universe: In astronomy, the sum total of all things which can be directly observed or whose physical effects on other things can be detected.

Variable Star: A star that changes its brightness. There are several classes of variable stars, including "periodic" variables (which change their brightnesses on a regular schedule, ranging from hours to many years) and "irregular" variables (which abide by no fixed schedule). Careful, long-term monitoring of variable stars is one major way in which amateur astronomers have made important contributions to research astronomy.

White Dwarf: The collapsed remnant of a relatively low-mass star (roughly one and a half times the Sun's mass or less), which has exhausted the fuel for its nuclear reactions and shines only by radiating away its stored-up heat. A typical white dwarf might have as much mass as the Sun, but have a size equivalent to the Earth's. Its density is roughly equivalent to that of a soda can into which a 747 airliner has been squeezed. (The Sun is expected to become a white dwarf at the end of its life.)

SECTION

3

TEACHING AND LEARNING

TEACHING ASTRONOMY

AND SCIENCE EDUCATION REFORM

by Cary Sneider

Lawrence Hall of Science
University of California at Berkeley

KEY IDEAS IN "TEACHING ASTRONOMY"

- Since the 1980's, educators, policy makers, scientists, and teachers have engaged in significant debate about science education reform. Some important areas of consensus have emerged:
    - The purposes of science education are to: 1) promote our national interest; and 2) promote the capacity of each individual to fully participate in modern society.
    - Special emphasis must be given to encouraging students from groups who have been historically underrepresented in the sciences, such as women and ethnic minorities.
    - Teaching facts and terminology is less important than involving students in activities that allow them to explore phenomena and solve problems.
    - Students should learn a variety of science topics from the early grades until they graduate from high school.
    - It is important to help students see connections among the various disciplines of science, mathematics, and the humanities, as well as between what they learn at school and the real world.
- Three major projects have developed frameworks for science education reform. These projects overlap in many areas, and differ in some respects. The activities in *Universe at Your Fingertips* reflect the framework developed in *Benchmarks for Science Literacy* of the AAAS. We selected *Benchmarks* because it offers the most extensive description of why students should study astronomy and what they should learn at each grade level.
- According to *Benchmarks*, "If being educated means having an informed sense of time and place, then it is essential for a person to be familiar with the scientific aspects of the universe and know something of its origin and structure."
- Today's reform efforts are not entirely new. Good science education has been going on for decades. Some of the best astronomy activities, which have been selected for inclusion in *Universe at Your Fingertips*, are both educationally effective and fun!

More than ten years ago the National Commission on Excellence in Education issued its report, *A Nation at Risk*, which recognized that the educational challenge facing our country was tantamount to "unilateral disarmament," and that if we didn't do something to turn around our system of science education, the United States would soon relinquish its role as a world leader.

A Nation at Risk was one of several alarming reports on the crisis of our educational establishment that were issued in the early 1980's. At the time, many in the U.S. felt that we were at war on two fronts—fighting a social and political battle with the Soviet Union, and an economic battle with Japan and other Asian economies. Since then, the Soviet Union has collapsed and Japan has suffered something of an economic recession.

But the emergence of the United States as the world's only superpower has not diminished enthusiasm for a strong system of science education in service of our national interest. *Goals 2000*, the statement of national educational goals supported by both the Bush and Clinton administrations and signed into law on March 31, 1994, as part of the Educate America Act, states that by the end of this decade, "U.S. students will be first in the world in math and science."

These reports and statements set off national debates about the purposes of science education, and a broader consensus has emerged. It is now widely recognized that science and mathematics education are not only necessary to promote our national interest among the community of nations, but also to promote the capacity of each individual to fully participate—both economically and intellectually—in modern society. These two goals are complementary, since it is only by empowering all citizens to participate in modern society that our nation can maintain world leadership. Special emphasis has been placed on finding new ways to encourage students from groups who have historically been underrepresented in scientific and technical fields, including girls and women, members of ethnic and cultural minorities, people with disabilities, and individuals who are learning English as a second language.

The growing national consensus on the importance and purpose of science and mathematics education has stimulated a wide variety of activities across the country. Congress has increased the financial support of science education tenfold in the past decade. Universities and professional societies have undertaken efforts to examine what is taught in schools, and to establish new guidelines for the content and process of science education. Now, in the 1990's, we are reaping the harvest of that early groundwork in the form of documents—variously called Frameworks, Benchmarks, and Standards—that suggest what students should know, how teachers should teach and assess student learning, and the training, materials, and systems that are required to support the recommended improvements.

Scientists and teachers who want to be in tune with the new reforms have no less than three major projects from which to choose in helping them to plan a science program for their students: *Project 2061*, developed by the American Association for the Advancement of Science; *Scope, Sequence, and Coordination*, developed by the National Science Teachers' Association; and the *National Science Standards Project*, being developed by the National Research Council of the National Academy of Sciences.

These three projects have different emphases, but in several areas they overlap and reinforce each other. All three support the ideal of science for everyone, not just those students who are most talented in science and mathematics. All three recommend that teachers should de-emphasize the teaching of facts and terminology, and increase the involvement of students in activities that allow them to explore phenomena, grasp new concepts, conduct experiments, and solve problems. All three recommend that students receive a balanced diet of various science topics from the early grades until they graduate from high school. All three recommend that teachers help students to see the connections among the various disciplines of science, mathematics, and the humanities, as well as the connections between what they learn at school and the real world of home and work. The following is a brief discussion of some of the differences among the three projects.

Project 2061 is named for the year Halley's Comet is expected to return to Earth, one average human lifetime after the comet's last appearance in 1986. The title reflects the project's aim, which is to change the nature and content of science education over the long term. With the philosophy that teachers should teach fewer concepts in greater depth, it was important to determine which concepts are essential and which can be omitted. To this end, Project 2061 convened teams of scientists to determine the essential science concepts that students should know by the time they graduate from 12th grade. The results were published in 1989 under the title *Science For All Americans.* The title of this volume further reflects the national consensus that science is not just for the most talented—but for everyone! Astronomy is prominently featured in this volume, in both Chapter 4, The Physical Setting, and Chapter 10, Historical Perspectives.

While *Science For All Americans* is highly regarded by both teachers and scientists, it has been criticized because it did not provide adequate guidance for teachers of elementary and middle school students. In 1993, in response to this criticism, Project 2061 published *Benchmarks for Science Literacy*, which provides guidance for teachers at different grade levels in how to prepare their students for achieving the goals outlined in *Science For All Americans.* Of all the documents that have been published so far, *Benchmarks* offers the most extensive description of why students should study astronomy (and other science subjects), and what they should learn at each level.

The astronomy activities selected for publication in *Universe At Your Fingertips* support both the content and the process of good science education that is described in the *Benchmarks.* Consequently, throughout this volume we will reprint a few choice quotes from the *Benchmarks*, to show why the activities are educationally valuable, and how they fit into the overall science program. We would like to start with the following selection from Section 4A, The Universe, which provides the best answer that we have seen for the fundamental question—why teach astronomy at all:

> *In earlier times, people everywhere were much more aware of the stars and were familiar with them in ways that few people today are. Back then, people knew the patterns of stars in the night sky, the regularity of the motions of the stars, and how those motions related to the seasons. They used their knowledge to plan the planting of crops and to navigate boats. The constellations, along with the Sun, the Moon, and the "wanderers"—the planets—have always figured in the efforts of people to explain themselves and their world through stories, myths, religions, and philosophies.*
>
> *For all of that, and for the sheer wonder the stars provoke on a clear, moonless night far from city lights—awe that has inspired the expressive powers of poets, musicians, and artists—science is not needed. Why, then, insist that everyone become familiar with the heavens as portrayed by science? Consider that in cities the night sky is no longer a familiar part of a person's neighborhood. Many people live today in circumstances that deprive them of the chance to see the sky often enough to become personally familiar with it. Fortunately, telescopes, photography, computers, and space probes make up the difference by revealing more of the cosmos in greater detail than ever before. Thus, science education can bring back the sky—not the same sky, but one that is richer and more varied than people's eyes alone had ever led them to imagine.*
>
> *Finding our place in the cosmic scheme of things and how we got there is a task for the ages—past, present, and future. The scientific*

> *effort to understand the universe is part of that enduring human imperative, and its successes are a tribute to human curiosity, resourcefulness, intelligence, and doggedness. If being educated means having an informed sense of time and place, then it is essential for a person to be familiar with the scientific aspects of the universe and know something of its origin and structure.*
>
> *In thinking about what students should learn about the heavens, at least three aspects of the current scientific view ought to be taken into account: (1) the composition of the cosmos and its scale of space and time; (2) the principles on which the universe seems to operate; and (3) how the modern view of the universe emerged.*
>
> *—Benchmarks for Science Literacy, page 61*

The Scope Sequence, and Coordination (SS&C) Project aims at restructuring science teaching at the middle and secondary levels. It recommends that every student take science every year for six years. Further, it recommends that the curriculum be carefully sequenced and coordinated so that the traditional science disciplines of physics, earth and space science, and biology and chemistry are spread out over several years, rather than being taught sequentially as they are at present. Such coordination would allow students to revisit concepts at successively higher levels of abstraction and to see connections between the various science disciplines.

The SS&C Project accepts the goals outlined by Project 2061. Both projects emphasize that teachers should not waste students' time and energy having them memorize hundreds of facts and terms; but should instead focus their energies on learning certain key concepts in depth, throughout their school careers. Like the *Benchmarks,* the SS&C *Content Core* lists the key concepts in each science area that are necessary for a person to understand in order to become scientifically literate. In this volume, key concepts in astronomy are classified under the heading *Earth and Space Sciences.* The following is a summary of major concept areas in astronomy from SS&C Volume I *The Content Core* (page 76).

Grades 6-8 - Earth-Moon-Sun system, the Sun as a source of energy, lunar craters and phases of the Moon, and the tides

Grades 9-10 - The solar system

Grades 11-12 - The origin and evolution of the universe, stellar evolution

We agree that these topics are appropriate for emphasis at these grade levels; but we hope that teachers would go beyond the "core," to explore other areas in astronomy as well. We are especially supportive of the emphasis given by the SS&C Project to the idea that students should study every science every year. Although this reform does not address the elementary grades, in our view the same principle applies there as well—students should study astronomy, beginning in kindergarten!

The National Science Standards Project is the most recent to offer a vision for future science education. Although several "working papers" have been released in recent years, the National Science Standards is not expected to be released to the general public until after this notebook is published. Like the other science framework projects, it emphasizes science education for all, and recommends that selected topics be taught in greater depth. And like the other projects, it emphasizes that students be involved in scientific inquiry, and not simply learn about science. Like Project 2061, it advocates that the important relationships between science and human affairs as well as connections with mathematics, technology, and history have their place in the science classroom. Like the SS&C project, key concepts in astronomy are listed under the general heading, *Earth and Space Sciences.* The project is distinguished by its further emphasis on the qualities of good science teaching, the importance of assessing student learning, and recommendations for establishing good science programs.

In selecting astronomy activities for your students it is good to keep in mind that today's reforms are not entirely "new." Good science education has been going on for decades. The great value of the reform projects has been to clearly articulate the qualities of good educational materials, and to legitimize the efforts of "maverick" science teachers, such as those who have felt it to be more valuable for their students to spend an extra period pursuing their own questions in the lab rather than "covering" the material in the book.

The astronomy activities included in the main body of *Universe At Your Fingertips* illustrate teaching methods that research and practice have shown to be both educationally effective and fun from the students' point of view. These activities also reflect the consensus on the qualities of good science education specified in all three of the reform documents described above. In the next article, "Learning Astronomy," we elaborate on what we mean by "educationally effective and fun."

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LEARNING ASTRONOMY

INSIGHTS FROM RESEARCH AND PRACTICE

by Cary Sneider
Lawrence Hall of Science
University of California at Berkeley

KEY IDEAS IN "LEARNING ASTRONOMY"

- If we are patient, students can develop inquiry skills while they learn fundamental concepts in astronomy.
- Many students have misconceptions about seemingly simple ideas such as the Earth's spherical shape, phases of the Moon, and the seasons. Educators now agree that it is important to address students' private theories in order for real learning to take place.
- Students who are not yet mature enough to engage in a certain kind of reasoning are likely to have difficulty understanding certain concepts. For example, young children often have difficulty seeing things from another point of view.
- Two-dimensional drawings can sometimes cause misunderstandings. Allowing students to manipulate three-dimensional models is often more effective in helping students to figure out certain phenomena.
- Students need to construct their own understanding of the universe by making observations, manipulating models, and struggling with their own theories.

Like many young teachers, I was a rebel. When I first studied astronomy in the fourth grade, I learned the names of the planets in order, and how to find the Big Dipper and Orion. My high school physics class included some astronomy which was a bit more challenging; but we devoted very little time to it. Then, at college, I experienced the excitement of research in astronomy and resolved that in the classroom I would not simply teach my students about astronomy; I would teach them how to be astronomers!

I did not, of course, expect that my students would become professional astronomers, but that they would do the kinds of things that astronomers do. They would observe the Sun, Moon, and stars, record their observations, identify patterns in the data, use scientific instruments to extend their senses, and construct models to explain the phenomena that they discovered. At the time, it seemed to me that these research skills were more important than understanding concepts that had been discovered by others.

After more than 20 years of teaching, curriculum development, and research in astronomy education, I have finally come to the conclusion that there is no real dichotomy between teaching students about astronomy and teaching them to be astronomers. It is important for students to learn research skills and to understand key concepts in astronomy. What brings these two goals together is the quality of patience.

Patience in teaching astronomy means giving up the idea that if we just tell our students "how it is," they will understand concepts such as gravity and seasons and phases of the Moon, and do well on the test. Instead, we need to allow students to observe and make sense of their own observations, and to struggle with explanations of astronomical phenomena. We still need to keep particular important concepts in sight as we plan activities for our students; but we also need to give up the idea that all of our students will reach the desired level of understanding by the time we complete the unit.

If we are patient, our students will learn the astronomer's skills of observing, finding patterns, and explaining what they see in the sky, at the same time that they gradually acquire the fundamental concepts of astronomy. The two goals are complementary, because students will understand and remember the concepts better if they learn them by acting like astronomers.

Although classroom teachers are the ones to help students to achieve these goals, professional and amateur astronomers can help a great deal by sharing what they do, and by being interested in the astronomy activities and discussions conducted by the classroom teacher. With both groups of educators in mind, I'd like to offer a few insights that I have gained through research and practice in teaching astronomy.

UNDERSTANDING THE EARTH'S SHAPE AND GRAVITY

My acquaintance with common misconceptions in astronomy began more than a decade ago with a symposium presented by Joseph Nussbaum, an Israeli educator whose research showed that when students in grades three through eight said the Earth is "round," many had some very strange conceptions of what was meant by that. For example, some thought that the Earth is round like a pancake, and Columbus sailed around it as he would around an island. Others meant that the round Earth is where astronauts go; it's not the same as the flat Earth where we live. Still others thought that the Earth we live on is indeed round, but that we live "on the flat part in the middle." Furthermore, Dr. Nussbaum found that many students who understood the spherical Earth concept were quite confused about gravity. Many wondered, "If people actually did live down there, on the other side of the world, why didn't they fall off?" Such bizarre ideas about the Earth's shape were held by a majority of students at the elementary grades, and by as many as 25% of the students in the eighth grade!

When I attended Dr. Nussbaum's symposium, I had been teaching for a few years and was a graduate student in education. When I shared these results with other teachers, they were indignant that their students might have such bizarre notions. So, we undertook a research project to determine if students in the San Francisco Bay Area shared these ideas about the Earth's shape and gravity. We interviewed 185 students in grades four through nine. We not only confirmed the results of earlier studies, but we also found that certain misconceptions, especially those concerned with gravity, persisted into high school. We compared our results with other studies and found that students in California held some of the same misconceptions as expressed in other parts of the world, from New York to Israel and Nepal.

Since we had the opportunity to interview so many students at such a wide range of grade levels, we decided that we would ask students about other topics in astronomy as well. We were not surprised that the youngest students expressed misconceptions, but we were astonished to find that many eighth and ninth graders did not understand some of the simplest ideas that they had read in their textbooks year after year. For example, many said that stars were tiny points of light, and some even believed that they were "sparks broken off of the Sun." Very few high school students could explain that the Moon sometimes appears as a crescent because only a small part of it is lit by the Sun. Most attributed the crescent shape as due to the shadow of the Earth on the Moon (which is true only during a lunar eclipse), or a result of clouds in front of the Moon.

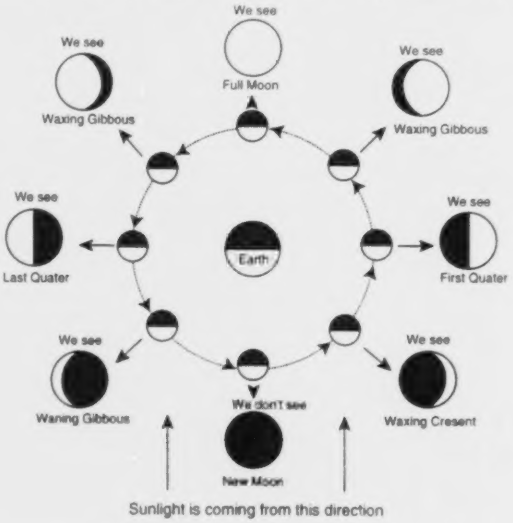
The teachers who participated in the study worked with me to develop and test classroom activities that would address some of these misconceptions. Over the years, some of the best activities that we developed found their way into the GEMS (Great Explorations in Math and Science) program at the Lawrence Hall of Science. The result was a GEMS Teacher's Guide entitled *Earth, Moon, and Stars*. The activities in this guide help students to understand the spherical Earth concept, so that they can use it as a model to solve problems, and to raise new questions, as well as understand further phenomena such as phases of the Moon and the apparent daily movement of the stars through the night sky. Two of the activities from *Earth, Moon, and Stars* are found in this book: Activity C1 "The Earth's Shape and Gravity," and Activity L3 "Ancient Models of the World."

WHY DO STUDENTS HAVE MISCONCEPTIONS?

Learning about students' misconceptions naturally raises the question, "Why?" Why do students have difficulty understanding simple concepts in astronomy, even after the same concepts have been explained over and over again, year after year? Why do students make up bizarre explanations in favor of those in their textbooks? Why do some students seem to understand these ideas more clearly than other students?

Several different kinds of explanations have been offered by educational researchers. One view is that students develop in their mental capacities as they mature, and that students who are not yet mature enough to engage in a certain kind of reasoning are likely to have difficulty understanding certain concepts. The researcher most closely associated with this point of view is the Swiss psychologist Jean Piaget. Piaget believed that people developed through a series of "stages" of increasing sophistication. Most elementary students are at the "concrete" stage, when they can reason about concrete objects and events, but have difficulty with abstract ideas. Most high school students are at the level of "formal operations," when they are able to reason abstractly. Differences between learners are explained in part by different rates of maturation.

For example, consider the phases of the Moon, which are often explained in textbooks with a rather complex diagram of the Earth and Moon, such as the one shown below. Such drawings typically show not only the positions of these bodies, but how the Moon would appear to a person standing on the Earth, at several different points in the diagram. A diagram of this sort is too abstract for many students to understand, so they fall back on a concrete explanation that they did learn successfully—such as the



(*Source:* The Universe in the Classroom, *Astronomical Society of the Pacific, Winter, 1988-89, page 1)*

Moon goes into the Earth's shadow (which explains lunar eclipses but not phases).

What is especially helpful about Piaget's theory is that it suggests a way to communicate difficult concepts—find a way to present them from the student's point of view, using concrete objects if at all possible. The way this idea is applied in teaching students about the Moon's phases is to bring the students into a room with just one bright lamp to represent the Sun. Tell them that their heads represent the Earth, and give each student a ball to represent the Moon. As they move the Moon in "orbit" around their heads, they see the Moon go through all of its phases. They also see the full Moon go into the Earth's shadow, modeling a lunar eclipse, and emerge as a full Moon from the other side of the shadow. This concrete activity helps students to see both phases and eclipses in the same model, and clearly separate the two explanations. (See activities A-3 "Modeling Moon Phases" and A-4 "Modeling Eclipses" in this book.)

Even adults who are learning about a new area tend to learn more easily if the teaching methods are concrete rather than abstract. This is made clear by the reactions of many teachers during workshops who say that they finally understand Moon phases and eclipses when they have an opportunity to use a concrete model of the Earth, Moon, and Sun.

A common misconception at the high-school level sometimes arises when we try to teach students about the H-R Diagram. In *Effective Astronomy Teaching and Student Reasoning Ability*, Dennis Schatz refers to Piaget's theory to explain a common misconception about the Hertzsprung-Russell (H-R) Diagram. The H-R Diagram plots a star's luminosity (brightness as viewed from a standard distance) against its color (which is an indication of its temperature). Through observations and simulations, astronomers have inferred typical evolutionary paths of stars which can be represented as "movements" on the H-R Diagram. As a star evolves, it would grow brighter or dimmer, and its temperature would change, so its position on the H-R Diagram would change. When these ideas are explained to high-school students, many think that the star physically moves on the diagram, as though it were a map of a region of space! They have great difficulty recognizing that the diagram represents two related quantities—luminosity and temperature—and that "movement" on the diagram represents a change in those quantities. One way to understand this difficulty is to suppose that the students are still at the concrete level. They perceive the H-R diagram as a picture of something that can move, not an abstract representation of two changing quantities. High school teachers may want to challenge themselves to find a way to teach the H-R diagram concretely!

Not all psychologists believe that students mature through stages in which their reasoning abilities significantly improve. Robert Gagné is one of a number of psychologists who have published theories in which intellectual development is the result of learning (and not the prerequisite of learning as suggested by Piaget). In other words, the more one knows, the easier it is to gain new knowledge.

In my personal opinion, both have a piece of the truth. Students seem to pass certain thresholds as they grow and mature, after which they can understand more complex and subtle concepts. On the other hand, it seems that the more students know about science the more they can do. For example, learning the concept of a controlled experiment can open new vistas to a young investigator.

SOME INSIGHTS ABOUT HOW STUDENTS LEARN

Of course there were good teachers long before there were any published theories of learning. As teachers we probably all have some ideas about how students learn best, and why some learn certain concepts more easily than others. Being explicitly aware of our own theories of learning can sometimes provide insights that are very valuable in the classroom. The following are some insights suggested by various researchers, theorists, and teachers. They are presented here in the hope that you will find them of value in teaching astronomy.

Insight #1. *Students often form new concepts by combining what they believed previously with what the teacher has to tell them.* For example, the Earth does not look like a ball, it looks flat. So, when their teachers tell them that the Earth is really shaped like a ball, they make up some very clever, and logical, model so they can continue to believe what they thought before, as well as what they learn in school. One of these models, expressed by some elementary students, is that "The Earth is round like a ball, but we live on the flat part inside." As a teacher, it is important for you to find out what your students' ideas are, both before and after teaching any new material. Ask questions, involve your students in discussions, or give them a problem or puzzle to solve, and you may be surprised at the many creative ways students have put together what you thought were very simple and straightforward concepts with what they thought was true before class. A good example of how to do this is Activity C1, "The Earth's Shape and Gravity," in which students grapple with several challenging questions about the "ball-shaped" Earth represented by a globe, and the "flat" earth of their everyday experience.

Insight #2. *Students need to "unlearn" misconceptions before they can learn new ones.* Since students invariably bring ideas to the classroom with them, it is important to give them time to discuss their ideas—no matter how bizarre—before they can integrate new knowledge. In our study, the students did not take their own ideas about the Earth's shape lightly. They really believed them! It was only when they had a chance to argue and debate their ideas with other students that many of them began to look for a new model that made sense to everyone. Even so, not everyone gave up their ideas, even though we followed open-ended discussions with clear explanations of "what scientists believe today." As educators we need to have the patience and faith that our students will eventually restructure their own thinking and correct their misconceptions over time, as long as we sow the seeds of self-examination and reflection. A good demonstration of how to do this is shown in Activity C2 "What Shape is the Earth?" In this activity students test their predictions about how shadows would appear on a flat or a round Earth.

Insight #3. *Students need to observe and record what they see, find and interpret patterns, make predictions, and formulate logical explanations for their own observations.* It's probably not a coincidence that the ancient Greek natural philosopher, Parmenides, who is said to be one of the first people to recognize that "the Moon borrows its light from the Sun," was also one of the first to propose that the Earth is shaped like a ball. Likewise, students seemed to be helped in understanding that the Earth is a ball when they learn about the Moon. An excellent series of activities in which students observe the cycle of lunar phases is found in Activities A1 and A2. In these two activities the students predict the order of Moon phases that they think they will see. Then, they observe the Moon for a month to check their predictions, and give their own explanations for why they think the Moon goes through phases. Making such observations and attempting explanations is a very important step that all students should experience—before the teacher or textbook tries to explain the phenomenon to them.

Insight #4. *Young children often have difficulty seeing things from another point of view.* The concept that the Earth is shaped like a ball is often presented by showing the students a globe, and asking them to imagine that they are a tiny ant, crawling on the globe. From the ant's point of view the globe is flat; but from our point of view the globe is shaped like a ball. The ability to imagine something from a different point of view develops gradually. Most first or second graders cannot do it, so when they are told about the Earth's spherical shape it doesn't make much sense. We teach so many things in astronomy that require students to see the Earth, Moon, Sun or planets from a viewpoint out in space, that it is no wonder they have difficulty understanding them! It is best either to wait until children are older to teach these concepts, or to devise a lesson in which they can see the phenomenon from their own point of view.

Insight #5. *Students' theories about some phenomena are related to their theories about other phenomena.* For example, we found that students' understanding of the Earth's shape was related to their theories of gravity. And their theories of the Earth's shape and gravity affected their understanding of Moon phases and seasons. This should not be surprising, since these ideas are logically interrelated. Some researchers have argued that students' understanding is poorly developed and fragmented, so that their explanations for some phenomena would not necessarily be consistent with other phenomena. But a series of studies by Vosniadou and Brewer has confirmed our observation that students' theories are nearly as consistent as are scientists' theories. That means if they misunderstand basic concepts such as the Earth's shape, they will misunderstand a great many other concepts as well. Compare your students' responses to the many different activities in this book, and try to understand how they are responding to the activities from their own point of view.

STUDENTS CONSTRUCT THEIR OWN IDEAS ABOUT THE UNIVERSE

All five insights lead to a single conclusion—students construct their own ideas of the universe. As teachers, we can help them to do this, but we cannot do it for them. Telling them isn't enough. Students must make their own observations, manipulate models, and struggle with their own theories. And if we want our students to continue their pursuit of science beyond our classrooms, we have to make sure that the process is not only educational, but fun!

These insights are reinforced in a powerful video entitled *A Private Universe,* created by a team of astronomers and educators at the Harvard-Smithsonian Center for Astrophysics (and available through the ASP's catalog.) In the video, Harvard graduates and faculty are interviewed about the seasons. It's startling to see that neither science majors nor professors are able to give an accurate astronomical rationale for the seasons! Further, the same misconceptions are given by students at a nearby high school. (Most incorrectly believe that summer and winter are caused because the Earth changes its distance from the Sun. In fact, it is the Earth's tilt that causes the seasons.) The video goes on to illustrate some of the very strong private misconceptions that students hold and how difficult it is to change their ideas. A hopeful note in the video is that students who engage in dialogue can change some, but not necessarily all, of their erroneous concepts.

A very good sequence of activities that avoids some of the problems shown in the video is Activities B3, B4, and B5, or Activities B8, B9, and B10. In both sequences of activities the students first observe how the Sun changes in its path each day and throughout the year, and then they create a concrete model to understand the seasons. (Check the activities to see which sequence would be best for your students.)

The video is only discouraging if we approach science teaching with the intention that all of our students must learn all that we have to teach them this year. If, on the other hand, we approach student learning with the attitude that we will have been successful if we change some of the students' understandings in some subjects, then we can succeed—not only in improving their conceptual understanding, but also in improving their abilities to observe the sky, discern patterns, and interpret their observations, just like thoughtful, critical astronomers. After all, even Galileo didn't figure out the orbits of the moons of Jupiter in a single observing session.

Of course, the same sentiment extends to your use of this Notebook. The next part of *Universe at Your Fingertips* contains a wealth of activities that will lead your students to a better understanding of the vast universe around them, but it would be a mistake to try and do all of them this year! Start with the ones that you are most comfortable with and that fit into your overall plan. Each year you can add several new activities, and retire those that are less exciting. In a very short time you will be fine-tuning a superb astronomy program for your students.

TEACHERS CAN HELP STUDENTS CORRECT THEIR MISCONCEPTIONS

I'd like to end this article with one additional research study which shows that students can change their understanding of concepts that are frequently misunderstood. In this case, the lesson that worked was a hands-on lesson in which students observed phenomena from their own point of view, and then were helped by the teacher to extend their understanding as far as the orbit of the Moon!

A few years ago I was visited by Varda Bar, a professor from Hebrew University in Jerusalem, whose career spans the fields of astrophysics and educational research. Professor Bar told me about a very interesting misconception that she had encountered. Many students believe that air is necessary for gravity to work. As she pointed out, this makes a great deal of sense from the student's point of view. Water waves need water, sound waves need air, so why shouldn't gravity need something to travel through as well? This misconception is reinforced when students see movies of astronauts floating around in their capsule. "There's no air up in space," they reason, "so there's no gravity either."

Dr. Bar arranged to visit Berkeley for a few months so that we could conduct a learning study with two classes of sixth graders. We were assisted by a graduate student, Nathalie Martimbeau. We interviewed students and gave them a written questionnaire. We found that 65% of the students thought that you could not have gravity where there was no air. Then we taught a class in which students observed the curved trajectories of balls as they rolled off tables. The students had no trouble explaining the trajectories as due to the ball's forward motion plus gravity. With some slides we helped the students extend the idea of a trajectory to a baseball that would be hit so hard it would go into orbit. We encouraged the students to argue and debate their various ideas about the role of gravity in maintaining the ball's orbit in space, where there is no air. Finally, we helped them extend the idea to a space satellite launched into orbit, and then the Moon in its orbit around earth. Each time we discussed how the orbit was caused by both the object's forward motion and gravity, even though there was no air. We tested the students again after the class, and found that the 65% who believed that you had to have air to have gravity had been reduced to only 21%.

This study is encouraging. It shows that many students can unravel misconceptions in a relatively short time, provided that they have concrete experiences, opportunities to discuss their theories with other students, and, of course, help from a knowledgeable and sensitive teacher.

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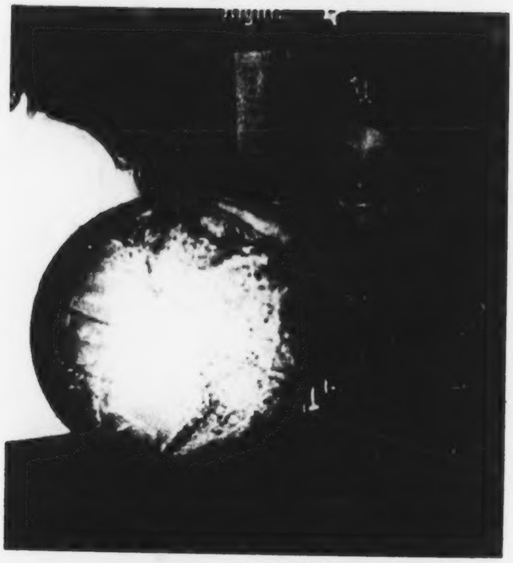
SECTION

4

ASTRONOMY ACTIVITIES



4 ASTRONOMY ACTIVITIES

Photo by Catherine Lombard

Astronomy Activities

to engage students in active learning

by Scott Hildreth
Chabot College, Hayward, California
and the Astronomical Society of the Pacific
and
Cary Sneider
Lawrence Hall of Science
University of California at Berkeley

KEY IDEAS IN "ASTRONOMY ACTIVITIES"

- The activities in this book have been carefully selected according to the following criteria: They address major concepts in astronomy for grades 4-9; they are clear and manageable; they are scientifically accurate; they engage students in active learning; and they are fun.
- The activities sample a variety of excellent sources. Many relate to other areas of the curriculum, and a few are only available in this book.
- While a course in astronomy is not needed to teach these activities, some background reading material or assistance from an amateur or professional astronomer is desirable.
- Activities are arranged by topic and grade level, and are placed in logical order; but feel free to put them in the order that makes most sense to you. Each section of activities is followed by one or more lists of resources.
- Although we do not suggest using activities at a lower grade level than recommended, most of the activities can be adapted for use with older students. Even college students can sometimes benefit by activities designed for sixth graders!
- Learning objectives are listed by major concepts, inquiry skills, and big ideas.

And now for the main course—a rich selection of 87 activities to help teachers and astronomers bring the stars and planets into the classroom. In our opinion, these activities embody the ideals and ideas expressed in the various documents concerning science education reform. They help students learn about astronomy by actually doing astronomy; and they help to communicate concepts by involving students in hands-on projects, such as observing and recording phenomena and manipulating concrete models.

HOW WE SELECTED THE ACTIVITIES

The staff at the Astronomical Society of the Pacific has been collecting astronomy activities from published and unpublished sources for more than ten years. We thus had a rich vein of activities to mine for this notebook. We started our activity search with the help of five outstanding teachers from a variety of grade levels who already do hands-on astronomy with their students. We agreed on several criteria that all activities had to meet. First, each activity addresses a key astronomical concept appropriate for students in grades 4-9. Second, each activity works in the classroom—the concept is presented clearly, in a way that is appropriate and manageable for students of the target age level. Third, the activities have been screened by astronomers to ensure that they are scientifically accurate. And finally, they engage students actively in learning, and they are fun!

Our selection was not intended to cover every possible topic in astronomy. (For example, we intentionally did not include aeronautical space science activities, although many of these could be used in an astronomy unit.) Instead, we chose materials from a variety of different sources, so that teachers and astronomers could learn more about the range of educational materials that are available. Like a selection of fine chocolates, if you find one you like, you can go back to the source and find several others that are equally delicious. Second, whenever possible we selected activities that might easily be related to social studies, mathematics, English, or some other aspect of the curriculum. And third, we included a few very good activities that were out of print, to ensure that they would not go out of existence.

HOW WE ARRANGED THE ACTIVITIES IN THIS BOOK

We have arranged the activities in sections by topic. Within each section the activities generally start with the lowest grade levels. Those at the same grade level are sequenced in a logical order. However, it is not necessary to do the activities in the order they are listed. Many teachers start their astronomy unit with constellations. Some prefer to start with the planets, and others begin by exploring light. It all depends on your own interests and your students—their grade level, and their personal preferences. Use your best judgment, and feel free to string the activities together in the order that makes the most sense to you. (For ideas, see the following pages for activity sequences used by Project ASTRO teachers.) It is very important to help your students see these connections as well, since it is often the recognition of connections between different astronomy activities that really helps students grasp what the science of astronomy is all about.

Each section begins with two short introductions—one to the subject matter and one to the activities. These introductions put the topic into perspective and explain why it should be included as an important part of every student's educational program. Further detail concerning the specific concepts that students should learn and experiences that they should have at various grade levels is provided through quotes from the Benchmarks for Scientific Literacy. (Although similar guideposts are provided by the NSTA's Scope and Sequence Project Core Curriculum and by the National Academy of Science's National Science Education Standards, the Benchmarks is emphasized in these sections because it provides the most detailed and comprehensive listing of concepts and experiences.)

Each section introduction also includes a list of the activities contained in that section in the form of a table, with a very short description of each activity, and the target grade levels recommended by the authors. (If no guidelines are given by the authors of the activities, the Editors of this book have provided their own estimates.) Please do not be limited by the grade levels listed! As demonstrated by the video *A Private Universe*, mentioned in the article *Learning Astronomy*, even college students can learn a lot from activities designed for sixth-graders!

LEARNING OBJECTIVES

Each activity is preceded by a single page that gives a somewhat more detailed description of the activity, the source of the activity, and what students are expected to learn from it. These learning objectives are divided into three areas: concepts, inquiry skills, and big ideas.

Concepts are astronomical phenomena, models, or theories that are central to a basic understanding of the science of modern astronomy. Concepts such as phases of the Moon, gravity, the features of planets and stars, and our location in the universe are among the ideas that all people should know to be scientifically literate. Through these activities your students will explore and become familiar with a great many key concepts in astronomy. But, as mentioned in the article on "Learning Astronomy," you should not expect that the activities will necessarily enable all of your students to give you an astronomer's explanation of the concept. On the other hand, all students should be able to say more about the concept after they have completed the activity, and they will certainly have advanced on their way to a more formal understanding later in life.

Inquiry Skills refer to what students are able to do. Activities generally give students practice in skills, and you would expect to see significant improvements in skill use when students have done several activities which use the same skills. So, you might want to select and sequence activities which build the same set of skills. Following is a list of skills that you can expect to see on the introductory pages to individual activities.

Big ideas are important guiding principles that cut across all the sciences, and which to a large extent define the nature of science. Project 2061's Science for All Americans and Benchmarks call these big ideas "themes." Since the term "theme" has previously been used to refer to major topics that weave through the curriculum, we prefer the term "big ideas." Big ideas are different from concepts in that they do not deal with specific phenomena, but are a way of looking at a vast array of different phenomena in a variety of fields. They differ from skills in that big ideas are a way of looking at and thinking about the world, rather than a specific technique that improves with practice.

IN CONCLUSION

Good activities are by no means the end of the story. In order to enjoy learning about the science of astronomy, students need enthusiastic and knowledgeable people to guide their explorations. At the very least, they need a person who is willing and interested in learning along with them.

These activities can be done by teachers without first taking a college-level course. However, some background knowledge about the concepts certainly helps, and we urge teachers to supplement their background if they feel the need to do so. At the end of each section is a short bibliography of resources which are both accurate and readable. These references should answer most questions and help teachers who are new to science—or astronomers who are new to teaching at this level—feel more confident and knowledgeable.

The best solution, of course, is the central idea of Project ASTRO—for teachers to work with professional or amateur astronomers to discuss the various concepts and phenomena; and, whenever possible, to actually do the activities together as a warm-up before presenting them in class. Matching teachers with amateur or professional astronomers is what Project ASTRO is all about. But even if you do not have an official connection to Project ASTRO, you can take the initiative to set up such a team in your community by contacting an astronomer (if you are a teacher) or contacting your local schools (if you are an amateur or professional astronomer).

If you are an experienced teacher or an astronomer who has visited classrooms before, you may already be familiar with some of these activities, and may even have tailored your own versions. If that is the case, we hope you will find some interesting twists on these traditional gems, along with suggestions on new ways to use them with students. We invite you to modify and extend these activities, and send us your best suggestions and new activity discoveries. (Please see form in the back of the book.)

A GLOSSARY OF SCIENCE OBJECTIVES

Many different lists of big ideas and inquiry skills have appeared in the science education literature over the years. Following is our own list and definitions of these powerful science objectives which your students will be practicing as they engage in the astronomy activities included in this book. Although the meanings of most of the words may be obvious, we thought you might find such a glossary a useful reference.

BIG IDEAS

Diversity and Unity When we look around us, we see tremendous differences. Earth is unique among the planets. Every moon in the solar system is different from every other moon. Even the stars differ from each other in temperature, composition, and luminosity. But there is also a unity to it all. All the planets revolve around the Sun in the same direction. All stars shine as the result of nuclear fusion. And spiral galaxies like our own can be found throughout the universe. Diversity and unity are two sides of a coin that give us clues for what to look for in our search to understand the universe.

Energy Energy is very difficult to define, but understanding how energy is changed from one form to another and transported through the universe is central to understanding how the universe came to be and where it is going. Students can observe energy in various forms around them, such as heat, motion, and chemical energy. By the use of instruments and observations they can see those same forms of energy millions of light years from their homes.

Evolution Evolution is the long-term history of a system. Understanding how our planet has evolved, how stars are born and die, how galaxies form and change, and how the entire universe came to be are all questions related to the evolution of systems.

Interactions Concepts usually involve understanding certain interactions—such as the interaction between the Earth and the Sun. Unlike relationships, which can simply be a description of how two bodies move with respect to each other, interactions involve physical forces and the exchange of energy between bodies.

Matter One of the fundamental properties of the universe is the kind and distribution of matter. From the composition of a planet or a star to what holds atoms and molecules together, questions about matter are fundamental to the science of astronomy.

Models One of the most powerful methods used by astronomers to explain a phenomenon is to create a representation, or model, of it and to see if the model behaves like the actual phenomenon. Students can create models with three-dimensional objects, or even with their own bodies. A model allows a person to see if their explanation for a phenomenon corresponds to the real thing. As representations, models are never perfect, but they can help us to understand certain aspects of phenomena.

Patterns of Change Astronomers make systematic observations over time because they expect the universe to change. Some patterns of change, like the daily movement of the stars, are cyclic. Other patterns show trends, such as the light from a supernova. Still other patterns are chaotic, like the ever-changing tail of a comet.

Scale Scale, the relative sizes of things, is one of most important concerns of the astronomer. A vast change in scale is required to go from the components of an atom to huge clusters of galaxies.

Simulations A simulation is a representation of how a model changes over time. For example, students can simulate the cycle of lunar phases with objects and their own bodies. Astronomers frequently create simulations on computers. The results of the simulations can then be compared with the actual phenomenon to see if the results are similar or different, leading to further understanding.

Stability A basic belief in science is that certain things, such as the laws of physics, do not change, for if they did we would not be able to learn anything about our universe. Through observations, students learn that cycles of the Moon, seasons, and the relative positions of stars are among the stable aspects of our world.

Structure Discovering structure, the form and arrangement of things, is one of the most important aspects of what astronomers do. Galileo's telescope helped to reveal the structure of the Sun, Moon, and planets. Today the Hubble Space Telescope is telling us more about the structure of faraway galaxies than ever before.

Systems Systems analysis is a way of looking at phenomena that emphasizes relationships and interactions as well as the inflow and outflow of matter and energy. We commonly think of the solar system, but it is also useful to think of a star or galaxy as a system.

INQUIRY SKILLS

Applying Students can apply a concept, theory, model, or technique by using it to solve a problem or create something that is useful, as in applying the principles of optics to develop a better telescope.

Calculating To calculate means to use arithmetic operations on real or simulated data to derive new quantities or find new relationships that would not be evident in raw data.

Classifying To classify means to identify attributes of objects or events that allow them to be placed into categories.

Communicating To communicate means to convey one's ideas or information to others.

Comparing In order to compare, students must identify similarities and differences between two objects or events.

Describing Students can use pictures or words to describe what they have observed or learned about a phenomenon.

Evaluating To evaluate means to use data and reasoning in order to make a decision about the value of a particular theory, or model.

Experimenting To experiment is to manipulate materials and equipment in order to discover the relationships between different variables.

Explaining Explaining a phenomenon usually means to provide a theory, hypothesis, or model to show causal relationships.

Exploring Your students explore as they use their senses to learn about a phenomenon with minimal guidance.

Graphing To graph means to display data on a coordinate grid so as to make visible the relationships between variables. Advanced graphing skills include interpolating and extrapolating.

Imagining Imagining means using creative thought to think of things that may or may not exist in reality. Imagination is as important to scientists as it is to artists and poets!

Inferring Inferring means drawing a logical conclusion from observations and evidence.

Measuring To measure means to use instruments and standards, such as rulers or light meters, to gather quantitative data.

Observing In astronomy, observing refers to systematic observation of astronomical phenomena, such as the changing positions of stars.

Ordering Ordering means to place in order along a single dimension, such as biggest to smallest, or oldest to youngest.

Organizing Organizing is to arrange equipment, data, or other materials in a way that helps to clarify ideas and relationships.

Predicting To predict means to use a theory, hypothesis, or model to say what will occur in the future.

Reasoning Reasoning refers to the use of logical thought to connect different ideas, to see possible consequences, or to make predictions.

Recognizing bias To recognize bias is to understand that everyone has preconceived ideas that might affect a person's ability to objectively collect data.

Recording To record means to use words, numbers, or pictures to write the results of observations onto paper or some other memory device so that the information can later be recalled and studied.

Using instruments Students can use a variety of equipment, such as telescopes and spectroscopes, to make systematic observations and measurements.

Visualizing To visualize means to create a mental picture of an object, event, theory, or model.

SAMPLE ACTIVITIES SEQUENCES

Below we outline the curriculum sequences developed by several Project ASTRO teachers using activities from *The Universe at Your Fingertips* and other sources. We provide these sequences to help you get started using the activities in this notebook. If you find it helpful, you may want to follow one of these sequences, modifying it by adding or deleting activities to fit your students' needs. Or, you may want to follow the content sequence these teachers used and select your own activities. These sample sequences are suggestions only. Many excellent activities are not included below. We encourage you to develop your own curriculum and sequence of activities using *The Universe at Your Fingertips* as you become acquainted with its contents. And, let us know if you have additional ideas for sequences to include in future versions of the notebook. (See the feedback form at the back of the notebook.)

GRADE 5
THREE MONTH ASTRONOMY UNIT
DONNA FLORES
NIGHTINGALE SCHOOL, STOCKTON, CA

Lead-In/Pre-Assessment Activities

1. Comfort Level in Astronomy Chart

How I Feel About Astronomy

Reaching for the Stars	Out of this world
In the Dark	Seeing the light

2. KWL (what I already know; what I want to know; what I already learned) Chart

Astronomy

What I Already Know	What I Want to Know	What I Learned

3. Picturing an Astronomer (M-6)
4. Finding the Music of the Spheres: Astronomy in Music (M-5)
5. Astronomy in the Marketplace (M-3) as ongoing project

The Earth and its Moon

1. The Earth's Shape and Gravity (C-1)
2. Predicting Phases and Features (A-1)
3. Observing Phases and Features (A-2)
4. Read *The Moon and You* by E.C. Krupp (available from the ASP catalog)
5. Modeling Moon Phases (A-3)
6. Show *Moon Kit* slides (available from the ASP catalog)
7. Astronomy laserdisc by Macmillan/MacGraw Hill (includes movement of the Earth and Moon, Tides, Moon Phases, and Eclipses)
8. Experimenting with Craters (E-1)

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The Planets and the Solar System

1. Planet Picking (C-9)
2. Ancient Models of the World (L-3)
3. Show *Powers of Ten* video
4. Toilet Paper Solar System Scale Model
5. *Splendors of the Universe* Slide Set (available from the ASP catalog)
6. The 12 Tourist Wonders of the Solar System (M-2)
7. *STV—Solar System Laserdisc* by National Geographic
8. Your Galactic Address (H-1)
9. *Planetary Taxi* CD-Rom by Visual Almanac

Telescope, Light and Spectrum

1. Light Bench Activities (simulation of making a telescope using a meter stick and lenses)
2. Light and Color—Activities from the FOSTER Project (J-4) (Or use Color Analyzers, GEMS Guide, from the Lawrence Hall of Science)
3. Astronomy laserdisc by Macmillan/MacGraw Hill (Light and the Spectrum)

Sun, Stars and Constellations

1. The Sun (B-1)
2. Making Pictures of Motion (B-6)
3. Making a Sun Clock (B-7)
4. Astronomy laserdisc by Macmillan/McGraw Hill (Sun and Stars)
5. The Reasons for the Seasons (B-5)
6. Read *The Big Dipper and You* by E.C. Krupp (available from the ASP catalog)
7. Three-Dimensional Constellations (F-8)
8. Create a Constellation (L-1)
9. Star Finding with a Star Finder (F-5)
10. Making a Simple Astrolabe from Making Measurements of Objects in the Sky (J-1)

Comets

1. Read *The Comet and You* by E.C. Krupp
2. Making a Comet in the Classroom (E-3)

GRADE 5
YEAR LONG INTEGRATED
EILEEN MITRO
PINER ELEMENTRY SCHOOL, SANTA ROSA, CA

Gravity

1. The Earth's Shape and Gravity (C-1)
2. Discussion about gravity on other planets. Try How High Can You Jump on Another Planet? (C-12)

Seasons

We link with Social Studies and geography topics, such as latitude and longitude.

1. Observing Where the Sun Sets (B-3)
2. The Reasons for the Seasons (B-5)
3. Making a Simple Astrolabe from Making Pictures of Motion (B-6)
4. Who Was Right? (M-1)

Moon Phases and the Moon Landscape

1. Classroom demonstation of phases of the Moon
2. Predicting Phases and Features (A-1)
3. Modeling Moon Phases (A-3)
4. Show *Moon Kit* slides (available from the ASP catalog)
5. Discuss history of Moon landings

Planets and Comets

1. Slides and discussion about the inner and outer planets and their statellites
2. Experimenting with Craters (E-1)
3. Making a Comet in the Classroom (E-3)
4. Show *Powers of Ten* video
5. Solar System Scale Model Sized to Your Room (D-5)

   Modification: Students choose a role out of a hat—all the planets, moons, asteroids and the Sun. They rotate the Sun in approximate scale.

Space Exploration and SETI

1. Decoding an Extraterrestrial Message (I-2)
2. Invent an Alien (I-6)

Stars and Constellations

1. Star Finding with a Star Finder (F-5)
2. Star Party! Use Looking Up: Observing the Nighttime Sky with the Unaided Eye (F-1)

GRADE 6

NINE WEEK ASTRONOMY UNIT

RUSS RACKOW

DIABLO VIEW MIDDLE SCHOOL, CLAYTON, CA

The Moon

1. Modeling Moon Phases (A-3) and Modeling Eclipses (A-4)
2. Observing Phases and Features (A-2)—ongoing
3. The Earth's Shape and Gravity (C-1)
4. The Thousand Yard Model (D-7)
5. Show *Powers of Ten* video
6. 3-D Model of the Earth and the Moon (D-2)
7. Predicting Phases and Features (A-1)
8. Discuss Moon observations

Sun, Stars, Galaxies and Constellations

1. The Sun (B-1)
2. Your Galactic Address (H-1)
3. Compare the Sizes of Stars (G-1)
4. How Many Stars? (H-3)
5. Star Finding with a Star Finder (F-5)
6. Creating Constellations (F-7)
7. Star Party

Space Exploration

1. Hello Out There: Message from Space (I-5)

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The Solar System

1. Can You Planet? (C-11)
2. Planet Picking (C-9)
3. The 12 Tourist Wonders of the Solar System (M-2). (Students select one planet to study and make a travel brochure for it.)
4. Invent an Alien (I-6)

For the last two weeks of the units, groups research different planets, prepare travel brochures and an oral presentation for the class. The "Invent an Alien" activity is presented and students work on their aliens at home, bringing them in on the last day of the unit. We videotape the students' presentations.

GRADE 3 AND GRADE 7

ONGOING ASTRONOMY UNIT IN CONJUNCTION WITH LIGHT AND COLOR STUDY

CHRISTINA WILDER, PAUL REVERE ELEMENTARY SCHOOL

ANN DEE CLEMENZA, MARTIN LUTER KING MIDDLE SCHOOL SAN FRANCISCO

Goal Student Familiarity with the Solar System, stars, satellites

Warm-Up

Show videotape of the Space Shuttle and Hubble telescope repair.

Earth and Moon

1. Observing Phases and Features (A-2)
2. Modeling Moon Phases (A-3)
3. Modeling Eclipses (A-4)
4. Map Apollo missions using a large Moon map and NASA Lunar Rock Certification materials.

Constellations

1. Creating Constellations (F-7) or Create a Constellation (L-1).

Students draw their own constellations and make up their own constellation stories. Later, 3rd and 7th grade students together perform Star Skits at an evening "Star-b-Que."

Planets

1. Can You Planet? (C-11). (We do not do it all. The Venn diagram was a hit and we did some of the graphing.)
2. "Tracking Jupiter's Moons" from the GEMS Guide, *Moons of Jupiter*, available from the Lawrence Hall of Science.
3. Experimenting with Craters (E-1) (Joint 3rd and 7th grade lesson.)
4. Making a Comet in the Classroom (E-3)
5. Building a Lunar Settlement (I-4) for the Galilean Moons

Stars

1. Light and Color Activitities from the FOSTER Project (J-4)

(Modification for younger students: Use diffraction gratings for each student and "Party bulbs"—colored light bulbs in red, orange, yellow, green, and blue, plus a good white light source (available from stores like Target for $2.50 each). Review the spectrum in order with your students. Use diffraction grating to see the spectrum of white light. Set up Party bulbs around the classroom and ask students to draw the spectra for each colored light bulb and to write one sentence comparing each colored bulb with the standard spectrum produced by white light. Emphasize careful observation and recording.)

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2. Compare the Sizes of Stars (G-1)
3. Among the Stars (G-2)
4. Star Finding with a Star Finder (F-5)

We ended with a joint 3rd and 7th grade "Star-b-Que" complete with cookout, Star Skits, and telescope viewing. We had a second Star Party near the end of the year with a slide show and dinner for families.

Grade 8

Nine weeks unit unit

Joy Reist

J.L. Stanford Middle School Palo Alto, CA

The Astronomy Unit is preceded by a study of matter and atomic structure.

Find out what the students already know!

- Make a list on the board of topics they might expect to cover.
- Have groups make lists of things students think they already know related to any of the topics.

Big Bang Theory

1. Discussion: Where did everything come from? Was there a beginning to our universe or was it always here? What do scientists think?
2. Have a student blow up a balloon filled with confetti until it pops (use safety goggles)
3. Show video clip on "How the Planets Were Formed" from *The Great Solar System Rescue* videodisc.
4. Cosmic Calendar (H-2)

Galaxies

1. Slide presentation on galaxy shapes and nebulas (available from the ASP catalog)
2. Read "Planets, Stars & Galaxies: A Grand Tour of the Universe" from *The Universe at Your Fingertips*.

Introduce Astronomer

(A Project ASTRO astronomer visited our class)

1. Read "What Astronomers Do" from *The Universe at Your Fingertips*.
2. Picturing an Astronomer (M-6)
3. Watch *Futures* career video about space

How Far Away

1. Read about light-years in "Background: Scale of the Solar System" from *The Universe at Your Fingertips*.
2. Watch *Powers of Ten* video
3. Your Galactic Address (H-1)
4. Hello Out There: Message from Space (I-5)

Stars

1. How Many Are Out There Anyway? (Palo Alto Unified School District)
2. Read "The Birth and Death of a Star" from *Ranger Rick's NatureScope: Astronomy Adventures* published by the National Wildlife Federation. (Extension: I turn off all the lights when I read this, using a

flashlight to see the print. At the last sentence I turn off the flashlight and slowly begin singing *Twinkle, Twinkle Little Star.* The kids "chime in.")

3. Birth and death of stars

The Sun—Our Star

1. Solar structure (see *Ranger Rick's NatureScope: Astronomy Adventures,* pp. 26; 34-35)
2. Show overhead or video on the Sun Light and the Electromagnetic Spectrum
1. Light and Color—Activities from the FOSTER Project (J-4) or *Color Analyzers,* GEMS Guide, available from the Lawrence Hall of Science

Solar System

1. Overview of the Solar System
2. Planet Picking (C-9)
3. Solar System Scale Sized to Your Room (D-5)
4. Making a Comet in the Classroom (E-3)
5. Invent an Alien (I-6) (Students also make a brochure about the planet to accompany the alien)

Earth and Moon

1. The Earth's Shape and Gravity (C-1)
2. Predicting Phases and Features (A-1)
3. Observing Phases and Features (A-2) (We take 2-4 weeks. You may want to start this activity earlier.)
4. Modeling Moon Phases (A-3) and Modeling Eclipses (A-4)
5. Experimenting with Craters (E-1)

Hold a Star Party!

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M Across the Curriculum: Interdisciplinary Teaching Ideas

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A

OUR MOON'S PHASES AND ECLIPSES

ACTIVITIES INCLUDED IN OUR MOON'S PHASES AND ECLIPSES

ACTIVITY	ESTIMATED GRADE LEVEL											
Grades	1	2	3	4	5	6	7	8	9	10	11	12
A-1. Predicting Phases and Features Students present their ideas about the sequence of the Moon's phases, and are encouraged to observe the actual phases.			▨	■	■	■	■	■	■	▨	▨	▨
A-2. Observing Phases and Features Students make a daily record over a month of the Moon's actual phases.			▨	■	■	■	■	■	■	▨	▨	▨
A-3. Modeling Moon Phases Students use Styrofoam balls illuminated by a light source to model the motion of the Moon around the Earth to discover what produces the Moon's phases.				■	■	■	■	■	■	▨	▨	
A-4. Modeling Eclipses Students use Styrofoam balls to model lunar and solar eclipses.				▨	▨	■	■	■	■	▨	▨	▨

■ - Grade levels recommended by authors ▨ - Can be extended to these grade levels

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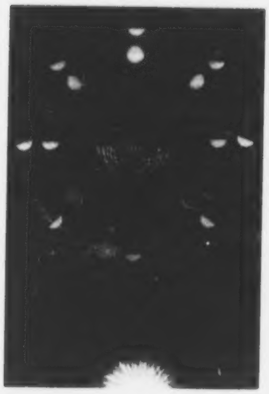
About the Activities:

Our Moon's Phases and Eclipses



KEY IDEAS IN "OUR MOON'S PHASES AND ECLIPSES"

- Once people evolved the capacity and desire to count and keep track of time, the monthly cycle of the Moon must have been one of their first discoveries.
- Modern scientific explanations for the Moon's ever-changing phases have roots in ancient mythology and the human desire to understand the world.
- The *Benchmarks for Science Literacy* suggests that the time for students to learn about Moon phases is at the 6-8 grade level.
- Students should observe and record the lunar cycle, act out the Sun-Earth-Moon relationships and make models, as recommended by the *Benchmarks*, and exemplified by these activities.
- Learning about lunar phases and eclipses together is very important for the students to be able to distinguish these concepts later on.

Nobody knows how the science of astronomy originated, many thousands of years ago, but it would not be surprising if it began with the Moon. The Moon offers the easiest opportunity to transform enjoyment of the majesty of the heavens into a predictive science. The Moon is the easiest object to find in the sky, and its pattern of repeating phases is hard to miss. Once people evolved the capacity and desire to count and keep track of time, the repeating cycle of the Moon must have become one of the first discoveries of early astronomers.

Still, understanding the Moon's monthly cycle is only part of what we would call "astronomy" today. The other part is understanding the cause of the Moon's ever-changing phase. The roots of such questions go back to mythology—early attempts to understand the regularities of the natural world, and synchronize natural phenomena with the activities of people. Today we reject such explanations as superstitious, but the many legends of the Moon's origin and its influence on people certainly grew out of real observations of phenomena such as tides and human menstrual cycles, as well as a desire to know and understand the world that still motivates scientific work today.

According to the *Benchmarks for Science Literacy* (page 62), at the K-2 level students should "observe how the Moon appears to change its shape. But it is too soon to name all the Moon's phases, and much too soon to explain them." At the 3-5 level, students should have opportunities to look at the Moon through telescopes, and to experiment with light. "How things are seen by their reflected light is a difficult concept for children at this age, but is probably necessary for them to learn before phases of the Moon will make sense." (*Benchmarks*, page 63.)

The *Benchmarks* suggests that the time to focus on Moon phases is at the 6-8 level. "By the end of the eighth grade, students should know that...The Moon's orbit around the earth once in about 28 days changes what part of the Moon is lighted by the Sun and how much of that part can be seen from the Earth—the phases of the Moon." (*Benchmarks*, page 69.) But achieving this outcome is not easy, and a method is suggested: "Moon phases are difficult because of the students' unfamiliarity with the geometry of light and 'seeing.' To help figure out the geometry, students can act out the Sun-Earth-Moon relationships and make physical models." (*Benchmarks*, page 66.)

The activities in this section provide the kinds of experiences and discoveries that are recommended by the *Benchmarks*. In Activity 1, "Predicting Phases and Features," students are asked to place pictures of the Moon, taken at different times of the month, in order. The activity is quick and easy, and it provides the teacher with an opportunity to find out what her or his students already understand about the lunar cycle. By asking students to explain why the moon takes these different shapes, she or he can better focus other lessons in the unit to address their level of understanding.

Activities 2 and 3 invite the students outdoors to observe the cycle of the Moon in the real sky for a month, and then to create a model—from each student's point of view—to explain the phases. Both activities are essential for students to grasp the concept, and realize that the explanation for phases that they learn in school applies to the real Moon that they can see in the sky. Perhaps for the first time, they will look at the Moon in a new light—as a huge sphere in the sky, lit by reflected light from the Sun.

The fourth activity supports the others in this unit because it helps students to separate two concepts that confuse many adults—lunar phases and eclipses. Students will see from this activity that although the Earth's shadow explains eclipses, it cannot possibly explain phases, since the Moon must be full when it enters or leaves the Earth's shadow. Learning both concepts together is very important for students to be able to distinguish the explanations later on.

BACKGROUND: OUR MOON'S PHASES AND ECLIPSES

Our planet's satellite, which we call the Moon, is the easiest astronomical object to observe. The only "scientific instrument" you need is a pair of eyes. The Moon is the only thing in the sky (other than the Sun) that doesn't look like a point of light or an indistinct fuzzy patch to the unaided eye. Even more interesting, the way the Moon looks to us continually changes. Keeping track of its appearance from night to night (or day to day) is a fascinating and easy way to get acquainted with the rhythms of change in the sky.

The Moon is small, only about a quarter the size of the Earth. Looking at its light and dark patches, many people are reminded of the face of a Man or the shape of a rabbit. Early astronomers who studied the Moon with the first telescopes were convinced that the dark areas were vast oceans, and so they named them "mare," the Latin word for "sea." We now know there is no water on the Moon; in fact, it's an arid, airless world, not hospitable to any kind of life. The maria (the plural form of the word "mare") are really large, smooth plains formed out of solidified lava.

The lighter patches are rocky regions covered with craters—circular pits or basins blasted out by high-speed impacts from rocks of varying sizes (from objects the size of small cities down to boulders and pebbles). Most of the craters bear silent witness to a time, billions of years ago, when collisions between such debris and planets were much more common. The Earth, too, experienced a similar bombardment, but erosion by wind, water, and the movement of the Earth's crust has largely erased ancient craters from the Earth's surface. On the Moon there is no wind or rain to wash away the evidence, preserving the cosmic history of our "neighborhood" for humans to study.

Over the millennia, the Moon has become "locked" into a special kind of motion around the Earth. It rotates on its axis at the same pace as it revolves around the Earth. As a result, the Moon always keeps the same "face" pointed toward us throughout its orbit. This is why astronomers speak of the "nearside" (the side we see) and "farside" (the side we never see) of the Moon. Indeed, it wasn't until the 1960s, when we sent spaceships to fly around the Moon, that we got our first glimpse of the far side of the Moon.

We only see the Moon because sunlight reflects back to us from its surface; it has no light source of its own. During the course of a month, the Moon circles once around the Earth.

Indeed, the word "month" comes from "Moon"; younger students really enjoy it if you give them permission to say "moonth" instead of "month" for a while.

The half of the Moon facing the Sun is always lit; but the lit-up side does NOT always face the earth! As the moon circles the Earth, the amount of its disk facing us that is lit by the Sun changes, altering how much of the lunar surface appears bright and how much is in darkness. The changes are known as phases, and repeat in a specific cycle each month. There are four primary phases: New Moon, First Quarter, Full Moon and Last Quarter. Each occurs about a week apart, with Last Quarter followed by another New Moon, which begins the cycle anew (it actually takes 29 and 1/2 days to go from one New Moon to the next). To understand the cycle of Moon phases, there really is no substitute to holding a small white ball in the light from a distant lightbulb and studying the changing shape of the illuminated part of the ball as you move it around you. The activities in this section demonstrate this quite well.

Several points about the Moon's phases should be emphasized. First, during the week it takes to move from one phase to another, the amount of the Moon's surface lit by the Sun changes gradually; it's not an abrupt change from one phase to the next (which is the impression some textbooks give). Second, the Moon is not limited to the night sky. Near both First and Last Quarter you can see the Moon during the daytime. (See the table at the end of this section for more on when you can see the Moon.) Finally, it's worth repeating that the phases of the Moon arise because of changes in how much of the lunar surface facing us is illuminated by sunlight as the Moon circles the Earth. The Earth's shadow plays no role in the Moon's phases.

But our shadow does darken the Moon during a lunar eclipse. Let's see why. The Earth circles the Sun once per year. The plane of the Earth's orbit is called the ecliptic. The Sun, the Earth and the Earth's shadow all fall within the plane of the ecliptic. The Moon circles the Earth once per month. The plane of the Moon's orbit is tilted a little bit (5°) from the plane of the ecliptic. When the Moon is on the side of the Earth away from the Sun (Full Moon), it passes very close to the Earth's shadow; so there is a chance of an eclipse every month. Because its orbit is tilted, however, the Moon usually passes just above or below the Earth's shadow. About once every six months the Moon goes right through the shadow of the Earth, creating a lunar eclipse.

Since the entire night side of the Earth faces the Moon when it is in its Full phase, everyone on the night side of the planet can see all or part of a lunar eclipse when it occurs. It takes the Moon a few hours to pass completely through the Earth's shadow. During that time, some parts of the Earth that were in nighttime when the eclipse started will rotate into daylight; people living there will miss the end of the eclipse. Similarly, parts of the Earth that were near sunset when the eclipse started will rotate into nighttime; for those people, the Moon will rise already in eclipse. Most of the Earth's night side, however, remains in darkness throughout the eclipse, enjoying the full spectacle.

While in the Earth's shadow, the Moon looks reddish-orange. This deep color comes about because the Earth's atmosphere bends the red-orange part of sunlight into the shadow, just as it does at sunrise or sunset (the sky appears reddish when the Sun is below the horizon). How dark the Moon appears depends upon whether the Moon is crossing through the center of the Earth's shadow or nearer to the edge of the shadow, and how much dust or pollution is in the Earth's atmosphere.

In an amazing coincidence, the Sun and the Moon appear to us to be almost the same size in the sky. Although the Moon is actually hundreds of times smaller in size than the Sun, it is, completely by chance, just as many hundreds of times closer to the Earth. Because of this, if the Moon happens to pass directly between the Earth and Sun, it can momentarily block out the Sun, creating a solar eclipse. This happens when the Moon is on the same side of the Earth as the Sun (New Moon). Again, because of the tilt of the Moon's orbit, it usually passes just above or below the Sun's position at this time. But, about every six months the Moon passes directly between the Earth and the Sun. Because the Moon's shadow is so small, however, only a small portion of the Earth's surface will see the Moon completely block out the Sun, a total solar eclipse. People outside of the small region of totality will see the Moon block only part of the Sun's surface, a partial solar eclipse; it looks like a "bite" has been taken out of the Sun.

The Moon is the only place in the entire solar system, other than Earth, on which humans have walked. The astronauts who landed on the Moon in the late 1960s and early 1970s returned with boxes full of rocks taken from the Moon's surface. Scientists continue to learn a great deal by studying these rocks. But our increasing scientific understanding of the Moon need not take away from our response to its beauty. To be startled by the Full Moon rising in the eastern sky at sunset is to be confronted by one of Nature's greatest spectacles. Knowledge need not reduce our sense of awe; it can enhance it.

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PHASE	RISES	EASTERN SKY	HIGHEST IN SKY	WESTERN SKY	SETS
New Moon	sunrise	morning	noon	afternoon	sunset
Waxing Crescent	just after sunrise	morning	just after noon	afternoon	just after sunset
First Quarter	noon	afternoon	sunset	evening	midnight
Waxing Gibbous	afternoon	sunset	night (pm)	midnight	night (am)
Full Moon	sunset	night (pm)	midnight	night (am)	sunrise
Waning Gibbous	night (pm)	midnight	night	sunrise	morning
Third Quarter	midnight	night (am)	sunrise	morning	noon
Waning Crescent	just before sunrise	morning	just before noon	afternoon	just before sunset

PREDICTING PHASES AND FEATURES

ACTIVITY A-1

GRADE LEVEL: 4-9+

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What's This Activity About?

What is the image that comes to your mind when you think of seeing our Moon in the sky? For many students, it is simply the familiar 'crescent-Moon' shape; for others, it is a bright 'full' Moon. Some students will picture a series of images related to the Moon's changing appearance, but their personal sequence is often incomplete or incorrect because they have never systematically *observed* the Moon's different shapes.

This activity investigates students' existing knowledge of the Moon's appearance, making their observations in the next activities more meaningful. It helps to uncover students' preconceptions about how the Moon's appearance changes, and is a great way to spark their curiosity about discovering the actual sequence of phases.

What Will Students Do?

Students will first draw an image of how they think the Moon looks and then discuss why their pictures may vary. Then they will analyze a series of lunar phase photos and sort them into a satisfactory sequence based on their experiences and ideas.

After creating their photo sequences, students can start an observation program over many nights to discover how the Moon's appearance actually changes.

Tips and Suggestions

- Use as an introduction to the Moon's phases, followed by the next activity, "Observing Phases and Features."
- One of the strongest parts of this activity-and often the hardest for teachers—is *not* providing the "correct" answers when students ask about the sequence of phases. By not revealing the answer, you will encourage personal observation and discovery.
- This activity can be adapted to model:
  -How the Sun moves across the sky during the day
  -How the Sun's position at dawn, noon, or dusk changes
  -How the different constellations move across the sky during the night

What Will Students Learn?

Concepts

Phases of the Moon
Positions of the Moon and Sun in the sky

Inquiry Skills

Visualizing
Ordering
Predicting
Inferring

Big Ideas

Patterns of Change
Systems

PREDICTING PHASES AND FEATURES

Everyone has a mental image of the moon. Often this is a single image, like the full moon. This activity investigates students existing knowledge of the moon's appearance, making their observations in the following activities more meaningful.

CONCEPTS

The moon follows a specific pattern of phases. Observable characteristics can be used to identify features of the lunar surface.

OBJECTIVES

Students will:
- draw their mental image of the moon.
- infer the sequence of the moon's phases based on observations of lunar photos.

MATERIALS

Lunar Photographs
scissors
pencil
tape or glue
sheets of blank paper

PROCEDURE

Advanced Preparation:
Make copies of the Lunar Photographs for each work group of two or three students.

1. Distribute sheets of blank paper. Ask students to close their eyes and create a mental picture that answers this statement: "When I think of the moon it looks like this to me." Have them draw their mental pictures on the blank paper.

2. Have students compare their pictures. Discuss why the pictures may vary.
   Teacher's Note: You should not judge the appropriateness of each drawing, or students' reasons for their drawings. Use the drawings and information as clues to their conceptions of the moon.

3. Divide the class into small work groups of two or three students. Distribute copies of the Lunar Photographs, tape or glue, scissors, and a sheet of blank paper to each work group. Have students cut out the photographs. Their goal is to place them on the sheet of paper in the order they think they would see them if they observed the moon throughout several weeks. Allow 5 to 10 minutes for them to work with the photographs.

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Teacher's Note: As each group completes its sequence, ask why the group chose its specific response. Do not judge the appropriateness of each sequence; rather, use the conversation to encourage students' deeper thinking and to give you a better idea of their understanding of lunar phases.

4. Once each group is satisfied with the order of the photos, students should tape or glue them to the blank sheet of paper. Have them number the pictures from one through six, in the order each would be seen. Be sure they indicate which way is up.

5. When all of the work groups have completed their photo sequences, have them move about the room to see the predictions of each group. Ask work groups to explain their reasoning for choosing the sequence they used. Encourage discussion of whether one sequence is more appropriate than another.

   Teacher's Note: It may be difficult, but this discussion should not lead to a conclusion about the most appropriate sequence. It should be used to set the tone for further discovery about lunar phases in the next activity.

6. Post the predictions on the bulletin board for reference during Activities Two and Three. During Activity Two, have students periodically review the photographs to determine whether they want to revise their predictions.

   Teacher's Note: If one carefully examines the lunar surface features, it is possible to determine the sequence in which the photos were taken—except the order may be reversed and the images upside down. At this point in the unit, you will not want to give away the answer to the sequence. Students will discover the appropriate sequence for themselves during Activity Two.

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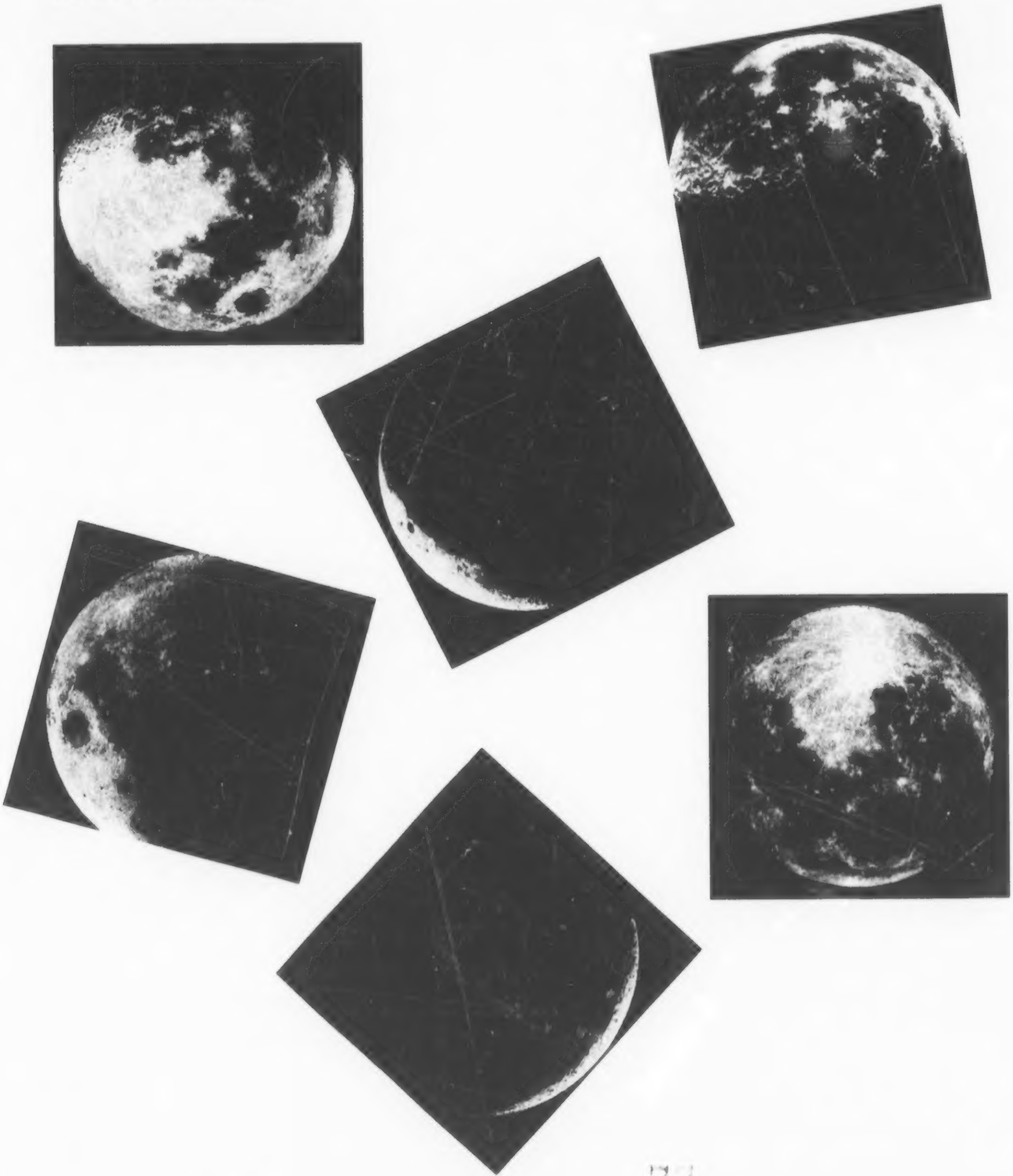
LUNAR PHOTOGRAPHS

Cut out each picture. Arrange them in the order you would expect to see the moon during the next several weeks.



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OBSERVING PHASES AND FEATURES

ACTIVITY A-2

GRADE LEVEL: 4-9+

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What's This Activity About?

This activity challenges students to observe the actual sequence of our Moon's changing appearance. It involves students in the process of scientific observation, and leads into the next activity, "Modeling Moon Phases," to further explore why the phases change. It is important to explore students assumptions about why the Moon changes before beginning this activity.

What Will Students Do?

Students will make a daily record of Moon observations over a month. Using their record, students refine their predictions about the Moon's phases, and determine the actual sequence of lunar phases.

Tips and Suggestions

- Encourage students to be as accurate as possible with their pictures, really observing which side of the Moon is lit, and even how the lit portion is "tilted," or angled toward the horizon.
- For earlier grades, family members can help students make their observations.
- It is best to start this activity around the "first quarter" phase, when the Moon is visible in the sky during the early afternoon. After reaching the full phase, the Moon will rise too late in the evening.
- Encourage students to look for the Moon in the early morning; many will be surprised that it is sometimes visible during the day.

This activity provides an opportunity to address students' own personal theories about the Moon's phases and to model how good observation techniques can help scientists contradict incorrect theories. Many people believe that phases of the Moon are different when viewed from different locations on Earth, or due to clouds covering a portion of the Moon's lit surface (these ideas will be explored further in the following activity). You might address some of the common misconceptions by having students observe the Moon consistently from their own special site, and record the weather for each observation. Or, after discussing misconceptions many people have, ask the students to create experiments to disprove these competing theories.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Phases of the Moon	Observing	Patterns of Change
The "month" of time related to lunar phases	Recording	
	Inferring	

OBSERVING PHASES AND FEATURES

Activity One establishes an understanding of students' prior knowledge of moon phasing and provides a reason to further explore this phenomenon. Activity Two challenges the student to learn more in order to determine the most appropriate photo sequence of moon phases. In this activity, students observe the moon during a two-week to one-month period, record their observations, and compare them to their sequence of photographs from Activity One.

CONCEPT

The moon follows a specific pattern of phases that can be observed and recorded.

OBJECTIVES

Students will:

- make a daily record of moon observations.
- use their observations to refine their predictions of the moon's phases.
- use their observations to determine the sequence of lunar phases.

MATERIALS

Lunar Observing Record Chart
pencil
binoculars (optional)
clipboard or other firm writing surface

PROCEDURE

Advanced Preparation:
Make copies of the Lunar Observing Record Chart. Look in an almanac, daily newspaper, or on a calendar to determine when the first quarter moon will be visible for the month you are planning this activity. It is best to start this activity two or three days before the first quarter.

1. Begin this activity on an afternoon when the first quarter moon is visible in the sky. Students may not realize the moon is often visible in the daytime as well as at night. This will allow you to help students do some daytime observations during the early part of this activity. With your assistance, students will be able to use their skills to make nighttime observations.

2. Distribute copies of the Lunar Observing Record Chart. Tell students they have an opportunity to determine the sequence of the moon photos from Activity One by observing the moon over the next two to four weeks.

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3. Explain how the Lunar Observing Record Chart is used:
   a. Go outside as a group and locate the moon. Record the date, time of the observation, and the shape of the moon. The pictures at the top of the Lunar Observing Record Chart will help students choose the most appropriate phase of the moon.

   Teacher's Note: If students ask what is meant by "waxing" and "waning", state that this will come in the next activity. A full explanation at this point will give away the results prematurely.

   b. Have students go out every clear day and repeat their observations. After the first observation, make a class activity of predicting what phase the moon will be in before the next observation.

   c. Post a classroom copy of the Lunar Observing Record Chart located on one wall of the classroom, where daily observations are summarized.

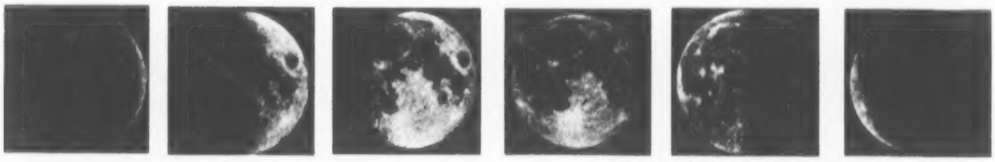
4. Students should work independently during the one to four weeks of observing, with periodic classroom updates on their observations.

5. As the students' observations progress, use their results to determine which of the sequences of lunar photos from Activity One is most appropriate. Several sequences are possible unless students know which part of the moon is at the top. If they do not realize this multiple possibility, you may need to point it out. Steer their discussion by suggesting that they look at the moon's surface features during subsequent observations to see which ones are near the top. This is a good time to introduce the different features visible on the moon, such as craters, maria, and rays.

GOING FURTHER

Advanced students may want to consider how their observations of the moon would vary if they lived in the Southern Hemisphere; for example, in Australia. This is a difficult problem for elementary level students, but a nice one which will encourage open-ended study.

Teacher's Note: Here is the most appropriate arrangement of the lunar photographs used in Activity One. The photo of the full moon in the background information can be used to determine correct orientation.



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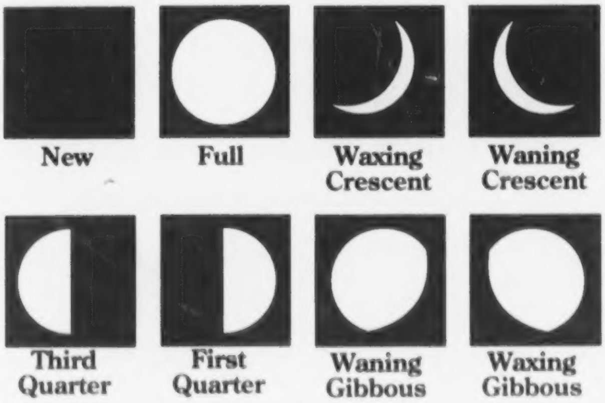
LUNAR OBSERVING RECORD CHART


New
Full
Waxing Crescent
Waning Crescent
Third Quarter
First Quarter
Waning Gibbous
Waxing Gibbous

Directions: Find the moon in the sky. Record the date and time in the box corresponding to the date. Shade the circle to show the moon's appearance.

SUN	MON	TUE	WED	THUR	FRI	SAT
○ Date ____ Time ____	○ Date ____ Time ____	○ Date ____ Time ____	○ Date ____ Time ____	○ Date ____ Time ____	○ Date ____ Time ____	○ Date ____ Time ____
○ Date ____ Time ____	○ Date ____ Time ____	○ Date ____ Time ____	○ Date ____ Time ____	○ Date ____ Time ____	○ Date ____ Time ____	○ Date ____ Time ____
○ Date ____ Time ____	○ Date ____ Time ____	○ Date ____ Time ____	○ Date ____ Time ____	○ Date ____ Time ____	○ Date ____ Time ____	○ Date ____ Time ____
○ Date ____ Time ____	○ Date ____ Time ____	○ Date ____ Time ____	○ Date ____ Time ____	○ Date ____ Time ____	○ Date ____ Time ____	○ Date ____ Time ____

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MODELING MOON PHASES

ACTIVITY A-3

GRADE LEVEL: 4-9+

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What's This Activity About?

With simple materials, students explore how the Moon's phases arise, why they change, and why a particular phase is visible at a certain time of night or day. Research has shown that students will cling to previous misconceptions about the reasons for lunar phases, even after hearing the correct explanation. This hands-on activity is perhaps the best way for students to confront their personal theories and discover the truth.

This popular activity not only demonstrates the reason for lunar phases, but also starts to develop students' sense of spatial perception as they create a mental image of the Sun, Moon, and Earth in space.

What Will Students Do?

Students use Styrofoam balls to simulate the Moon, which will be lit by a single light source in the classroom. They observe how different portions of their ball are illuminated as they hold it in various positions. They will create a complete series of phases matching the Moon's appearance. They will relate lunar phases to the positions of the Earth and Sun.

Tips and Suggestions

- This activity works best in a very dark room with a very bright light. Leave time to prepare if your classroom is not easily darkened, or a bright light is not easy to find. Dark colored plastic garbage bags work well to cover windows. An overhead projector can work as the light source.
- Because the visualization in this activity can be difficult for some students, it is helpful to do this activity with a smaller group while the rest of the class works on their moon phase chart or another project, or to do the activity more than once.
- Students will usually observe that their own shadows will cover the Moon ball when it is opposite the light source, simulating a lunar eclipse during the "full Moon" phase. Ask them to hold the Moon ball above or below the shadow of their head, and ignore the eclipse for the time being. Eclipses will be addressed in the next activity.
- To address students' misconceptions, before doing the activity ask the class to list possible explanations for the phenomena of lunar phases. Do not comment on the validity of the theories offered. Ask each student to write down their own explanation, based on what they have heard. After the activity, rewrite their explanation for phases and discuss any changes from earlier ideas. Have students do this activity at home with their families, or demonstrate to younger students and then write about their results.
- You may purchase Styrofoam balls from: Molecular Model Enterprises, 116 Swift St., P.O. Box 250, Edgerton, WI 53334, (608) 884-9877.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Phases of the Moon	Explaining Observing Reasoning Recognizing Bias	Patterns of Change

MODELING MOON PHASES

This activity allows students to use models of the sun, earth, and moon to discover why the moon phases occur.

CONCEPT

The observed phase of the moon is determined by its position relative to the earth and sun.

OBJECTIVES

Students will:

- be able to state the order of the moon's phases from one full moon to the next.
- demonstrate how the moon's position relative to the earth creates the phases.

MATERIALS

light bulb on a stand or clamp (or lamp with its shade removed)
extension cord
one Styrofoam ball or light colored sphere for each student (as model moon)
pencil and paper
darkened room

PROCEDURE

Advanced Preparation:

Collect enough Styrofoam balls to have one for each student. Be sure that there is plenty of space for students to stand and move about as they work through this activity. Check that the lamp or light bulb for the model sun works properly and that it can be placed in the front of the room where everyone can see it. The room will need to be completely dark for this activity.

1. Review the results of Activity Two, which showed that the moon goes through a sequence of phases. Work with the students to review the order of the phases from one full moon to the next.

2. Explain that to understand why the phases of the moon occur, students need to look at models of the moon, earth, and sun. Place the lamp in front of the room. Remind students of safety near the hot light bulb and electrical cord. Have students stand in a semicircle facing the lamp. Explain that the lamp represents the sun and that their head represents the earth, with their nose being their hometown.

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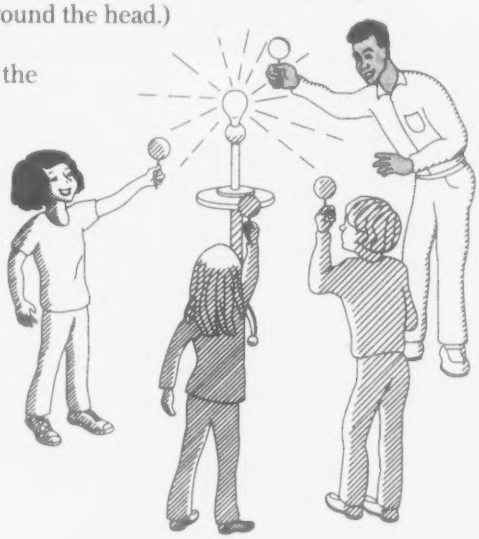
3. Ask students to stand so it is noon in their hometown. If disagreement occurs, have them discuss this until it is agreed that noon is when their nose is pointed toward the "sun." Ask them to stand so it is midnight. They should turn so they face away from the "sun." Ask them to stand so it is sunrise and sunset. In order to stand properly, they will need to know their "earth" head rotates from right to left, with their right shoulders moving forward. Practice the ideas of sunrise, noon, midnight, and sunset until you feel that the students have a good understanding of these relative positions.

4. Distribute one Styrofoam ball moon model to each student. Have students stick a pencil into the ball to make it easier to hold and not interfere with their ability to observe the phases of the moon model. Have students hold the moon model at arm's length. Allow time for them to explore how the sun's light reflects off the model as they place their moons in different positions around their "earth" head.

5. Choose one of the lunar phases and ask students to find the position in the "moon's" orbit where that phase is visible. (First quarter is a good phase to start with.) Encourage students to compare their results and discuss differences. Ask one student who has the correct position to state why it is right. As the teacher, you can check for understanding by seeing if all of the students are standing in the same position.

6. Have students model the other phases; for example, full moon, third quarter, and new moon. As they learn where to hold the Styrofoam model for each phase of the moon, challenge them to determine the direction the real moon travels around the earth to create the phases in the correct order. (This can be demonstrated by moving the ball from right to left in orbit around the head.)



7. Allow time for students to experiment with the movement of the moon. Have them work together to draw a diagram of the moon's position in order to create each of the phases. Ask students to state what causes the phases of the moon. (The spinning earth—your head—makes the moon rise and set each day, but this does not affect the phase of the moon. The phases are caused by movement of the moon around the earth.)

8. Have students check their positions for the moon against those in the moon phases diagram that follows.

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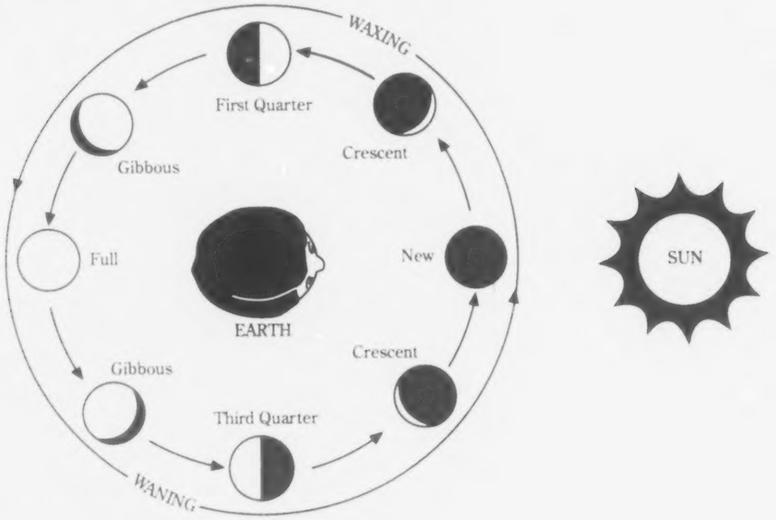
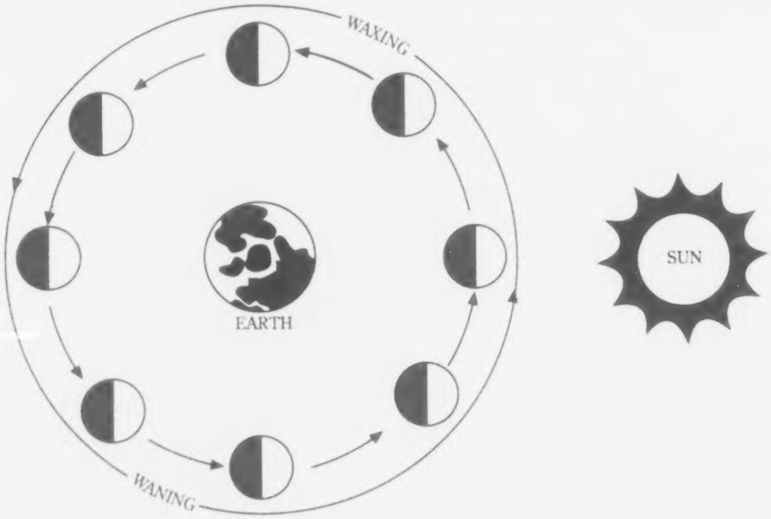
THE MOON AS SEEN FROM EARTH


WAXING
First Quarter
Crescent
Gibbous
Full
EARTH
New
SUN
Gibbous
Crescent
Third Quarter
WANING

THE MOON'S POSITION RELATIVE TO THE EARTH AND SUN AS VIEWED FROM OUTER SPACE, ABOVE OUR SOLAR SYSTEM


WAXING
EARTH
SUN
WANING

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MODELING ECLIPSES

ACTIVITY A-4

GRADE LEVEL: 6-9+

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What's This Activity About?

The Moon phase modeling activity can also be used to simulate both lunar and solar eclipses. Lunar eclipses occur when the Earth's shadow falls on the Moon during the "full" phase. The Moon will darken significantly (but not disappear). Solar eclipses occur when the Moon passes between the Earth and Sun, temporarily blocking sunlight over a small portion of our planet's surface.

With the Styrofoam balls and light of the preceding activity, students will see that their shadow occasionally covers the Moon ball, creating a lunar eclipse. They can also observe the Moon ball's shadow sometimes covering their face, blocking the light, creating a solar eclipse. The activity has background information and pictures to explain why both types of eclipses occur.

What Will Students Do?

Students will simulate solar and lunar eclipses using Styrofoam balls and a single light source. They will observe how both types of eclipses occur, predict when eclipses are likely to occur, and consider whether more people will be likely to see a lunar or solar eclipse.

Tips and Suggestions

- Note that the Moon is an average of 30 Earth diameters away from the Earth. This is much greater than textbook diagrams can show. Such diagrams can mislead students into thinking that eclipses should happen each month.
- The hula hoops are helpful in demonstrating the orbit of the Moon around the Earth, and the relative positions of the Moon and Sun, but may be confusing to some students because the Sun is so much farther away (about 400 times farther away than the Moon). The activity can be done quite successfully without the hoops.
- For older grades, discuss what happens when only a portion of the bulb is blocked by the Moon ball (a partial eclipse), or when the ball appears smaller than the light bulb (an annular solar eclipse). These events are usually illustrated in high school astronomy texts.
- Most astronomy software include eclipse demonstrations. Some programs (*Voyager* for the Mac, *The Sky* for DOS and Windows, among many others) can automatically predict the date, time, and locations of upcoming eclipses and simulate the exact views seen from Earth. These programs are especially helpful in comparing different views of eclipses seen from different locations on Earth.
- You may purchase Styrofoam balls from: Molecular Model Enterprises, 116 Swift St., P.O. Box 250, Edgerton, WI 53334, (608) 884-9877.

What Will Students Learn?

Concepts
- Solar Eclipses
- Lunar Eclipses
- Phases of the Moon
- Orbit of the Moon around the Earth

Inquiry Skills
- Experimenting
- Observing
- Reasoning
- Predicting

Big Ideas
- Patterns of Change
- Interactions
- Models

MODELING ECLIPSES

This activity explores why, when, and how often solar and lunar eclipses occur, using the earth, moon, and sun models of Activity Three.

CONCEPTS

Eclipses are caused by a predictable alignment of the earth, moon, and sun. Different alignments create lunar and solar eclipses.

OBJECTIVES

Students will:

- distinguish between lunar and solar eclipses.
- model how lunar and solar eclipses occur.
- predict when an eclipse is most likely to occur.
- determine whether more people can see a total lunar or total solar eclipse.

MATERIALS

light bulb on a stand or clamp (or lamp with its shade removed)
extension cord
one Styrofoam ball or light colored sphere (as model moon)
pencil and paper
two hula hoops

PROCEDURE

Advanced Preparation:
Read the eclipse information at the end of this unit for a more thorough understanding of eclipses.

1. Ask students if they know the definition of an eclipse and the difference between a solar eclipse and a lunar eclipse? Explain that this activity will help them understand the difference between these two types of eclipses and why they occur.

2. Set up the equipment as it was used in Activity Three, with students in a semicircle facing the lamp. Have them move the moon ball in orbit until it completely blocks their view of the lamp. Explain that when the moon is positioned between the earth and the sun, and it blocks the sun, it produces a solar eclipse. Students can remember this by thinking of the view of the sun as being clipped off. Have students position themselves so that the view of the full moon is clipped off by the earth's shadow. Ask them to tell you what phase the moon must be in to produce each type of eclipse.

87

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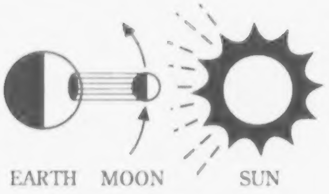
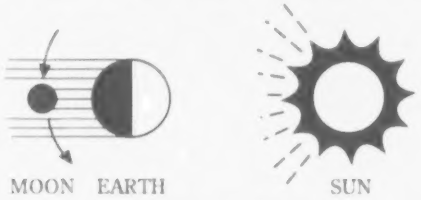


Total Solar Eclipse
Moon must be in new phase. Only people in a small region on earth where the moon's shadow falls can see the total solar eclipse.



Total Lunar Eclipse
Moon must be in full phase. All people on the night side of the earth can see lunar eclipse.

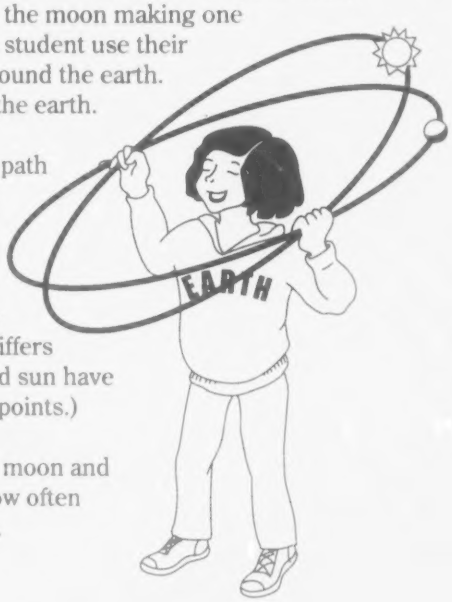
3. Now that students know what causes eclipses, ask them to predict how often there should be solar and lunar eclipses, and whether more people get to see a total solar eclipse, or a total lunar eclipse. Give them time to work with the moon ball model before guiding them to the answers.

4. Although solar and lunar eclipses occur with equal frequency, a person is less likely to see a total solar eclipse than a total lunar eclipse. Ask students to take partners. Have one partner hold the moon ball to produce a solar eclipse. Have the other person look at the shadow of the moon falling on the face of his/her partner. Ask students to consider this question: if the student's head were the earth, from what part of the earth could people see the solar eclipse? Have the partner hold the ball to produce a lunar eclipse. Ask if more people will see a lunar eclipse or a solar eclipse. Generate a list of predictions for how often solar and lunar eclipses should occur, along with reasons for the answers.

5. Hold two hula hoops over your head, as shown in the illustration, to show the relationship of the path of the sun and the moon ***as seen from earth*** (your head). The inside hoop is the orbit of the moon, with the moon making one complete revolution each 29.5 days. Have one student use their moon model to follow the path of the moon around the earth. Discuss the route the moon takes as it orbits the earth.

6. The outer hoop represents the sun's apparent path as seen from earth, with the sun appearing to go around the earth once a year. (Although the earth actually goes around the sun, our view from earth makes the sun appear to go around the earth.) Have one student trace the path of the sun around the hoop. Ask how it differs from the moon's path. Where do the moon and sun have to be to produce an eclipse? (At the crossing points.)

7. Use the students' knowledge of how often the moon and sun are at the crossing points to determine how often eclipses occur (see Background Information).



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RESOURCES FOR EXPLORING THE MOON

by Andrew Fraknoi
Astronomical Society of the Pacific
390 Ashton Avenue
San Francisco, CA 94112

Books and articles marked with a • are especially useful for those just becoming familiar with the subject

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

Phases of the Moon

Any introductory textbook on earth science or astronomy will have a section on the Moon and its phases. See also:

• Coco, M. "Not Just Another Pretty Phase" in *Astronomy*, July 1994, p. 76.

Schatz, D. & Cooper, D. *Astro Adventures: An Activity Based Curriculum*. 1994, Pacific Science Center, Seattle. Includes excellent activities on the phases of the Moon, many of which are reproduced in this Notebook.

Observing and Photographing the Moon

• Kitt, M. *The Moon: An Observing Guide for Backyard Telescopes*. 1992, Kalmbach. An 80-page illustrated guide to observing and understanding lunar features and changes.

Price, F. *The Moon Observer's Handbook*. 1989, Cambridge U. Press. A useful guide for amateur astronomers.

MacRobert, A. "Close-up of an Alien World" in *Sky & Telescope*, July 1984, p. 29.

• Chaikin, A. "A Guided Tour of the Moon" in *Sky & Telescope*, Sep. 1984, p. 211. For beginners.

Kitt, M. "Observe the Apollo Landing Sites" in *Astronomy*, Jul. 1989, p. 66. Guide for serious observers.

• Coco, M. "Staging a Moon Shot" in *Astronomy*, Aug. 1992, p. 62. Instructions on photography for beginners.

McConnell, D. "Basic Lunar Astrophotography" in *Astronomy*, Dec. 1985, p. 69.

The Moon as a World

• Hockey, T. *The Book of the Moon*. 1986, Prentice Hall. Excellent introduction by an astronomer/educator.

Moore, P. *The Moon*. 1981, Rand McNally.

Brownlee, S. "A Whacky New Theory of the Moon's Birth" in *Discover*, Mar. 1985, p. 65.

Bruning, D. "Clementine Maps the Moon" in *Astronomy*, July 1994, p. 36.

Morrison, D. & Owen, T. "Our Ancient Neighbor, the Moon" in *Mercury*, May/Jun. 1988, p. 66 and Jul/Aug. 1988, p. 98.

Benningfield, D. "Mysteries of the Moon" in *Astronomy*, Dec. 1991, p. 50.

• Ryder, G. "Apollo's Gift: The Moon" in *Astronomy*, July 1994, p. 40.

The Apollo Program: Exploring the Moon

• Chaikin, A. *A Man on the Moon*. 1994, Viking Press. A nice history of the human exploration of the Moon.

Cooper, H. *Apollo on the Moon.* 1970, Dial Press. A science journalist's vivid account.

Lewis, R. *The Voyages of Apollo: Exploration of the Moon.* 1974, Quadrangle Books. Another good science writer's summary.

Murray, C. & Cox, C. *Apollo: The Race to the Moon.* 1989, Simon & Schuster. A popular-level account, from many interviews with the participants.

Chaikin, A. "The Moon Voyagers" in *Astronomy,* July 1994, p. 26.

Hurt, H. "I'm At the Foot of the Ladder" in *Astronomy,* July 1989, p. 22. Article with many photos commemorating the 20th anniversary of the first lunar landing.

Weaver, K. "First Explorers on the Moon: The Incredible Story of Apollo 11" in *National Geographic,* Dec. 1969.

SELECTED READINGS FOR STUDENTS

Grades 4-6

Asimov, I. & Walz-Chojnacki, G. *The Moon.* 1994, Gareth Stevens.

Blumberg, R. *First Travel Guide to the Moon.* 1980, Four Winds Press. A cute "tourist guide" to a future Moon colony, teaching quite a bit of space science as it proceeds.

Couper, H. & Henbest, N. *The Moon.* 1987, Franklin Watts.

Darling, D. *The Moon: A Spaceflight Away.* 1984, Dillon Press.

Simon, S. *The Moon.* 1984, Macmillan.

Villard, R. "Astronomy on the Moon: Opening a New Window to the Universe" in *Odyssey,* 1992, issue 7, p. 16. Future observatories that could be built on the Moon.

Grades 7-9

Apfel, N. *The Moon and Its Exploration.* 1982, Franklin Watts.

Davis, D. & Hughes, D. *The Moon.* 1989, Facts on File. Dramatic art and good information.

Sullivan, G. *The Day We Walked on the Moon.* 1990, Scholastic Inc.

SELECTED AUDIOVISUAL MATERIALS

There are more than a dozen NASA videos on the exploration of the Moon and what we learned. Contact the NASA Teacher Resource Center nearest you or write to NASA CORE (see the address under organizations).

Apollo 11 at 25 (Software for Mac's from the Astronomical Society of the Pacific) Images of lunar exploration with background information.

The Apollo Moon Landings (video from Finley-Holiday Films) Review of moon exploration.

The Moon Kit (1987 slide set, Astronomical Society of the Pacific) 18 slides and an extensive booklet for teachers, emphasizing the geology and history of the Moon.

Apollo Landing Sites (1991 slide set, Lunar and Planetary Institute) Shows where on the Moon the manned missions landed. Call (713) 486-2172.

One Small Step (1978 video, Vestron Video) An episode of the NOVA TV series on the many steps that made the Moon landing possible.

Moon Shot (1994 video, Astronomical Society of the Pacific) 3 hour video, narrated by astronauts.

Cosmic Clips (1993 video, Astronomical Society of the Pacific) Collection of short videos, including one simulating the new theory of forming the Moon by a giant impact.

RESOURCES FOR EXPLORING ECLIPSES OF THE SUN AND MOON

by Andrew Fraknoi
Astronomical Society of the Pacific
390 Ashton Avenue
San Francisco, CA 94112

Books and articles marked with a • are especially useful for those just becoming familiar with the subject.

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

Books on Eclipses

• Littmann, M. & Willcox, K. *Totality: Eclipses of the Sun.* 1991, U. of Hawaii Press. Excellent introduction to the science, history, and lore of eclipses.

• Harris, J. & Talcott, R. *Chasing the Shadow: An Observer's Guide to Eclipses.* 1994, Kalmbach Publishing. Designed for amateurs; good practical guide.

Pasachoff, J. & Covington, M. *Cambridge Eclipse Photography Guide.* 1993, Cambridge U. Press.

Allen, D. & C. *Eclipse.* 1987, Allen & Unwin. Introduction by an Australian astronomer and his wife; hard to obtain in the U.S.

Krupp, E. *Beyond the Blue Horizon.* 1991, Harper Collins. Includes a good section on eclipse myths from many cultures.

Articles On Eclipses of the Sun

Anderson, J. "Eclipse Prospects for the 1990's" in *Astronomy,* Feb. 1989, p. 71. Information on the next eight total solar eclipses.

Dickinson, T. "The Eclipse Cult" in *Mercury,* Jan/Feb. 1990, p. 20. Lists solar and lunar eclipses between 1990 and 2000.

• Dyer, A. "When Worlds Align" in *Astronomy,* Jul. 1991, p. 62. A guide to the July 91 total eclipse of the Sun, but full of good observing hints for any solar eclipse.

• Gingerich, O. "The Making of A Prize Eclipse" in *Sky & Telescope,* July 1991, p. 15. On eclipse cycles, and when the longest eclipses occur.

Harris, J. "Confessions of an Eclipse Addict" in *Astronomy,* Jan. 1988, p. 62.

Kundu, S. "Observing the Sun During Eclipses" in *Mercury,* Jul/Aug. 1981, p. 108. What scientists learn observing eclipses today.

• Menzel, D. & Pasachoff, J. "Solar Eclipse: Nature's Superspectacular" in *National Geographic,* Aug. 1970.

Pasachoff, J. & Ressmeyer, R. "The Great Eclipse" in *National Geographic,* May 1992, p. 30. The above two are beautifully illustrated reports on some recent eclipses.

Pasachoff, J. & Espenak, F. "Videotaping the Eclipse" in *Sky & Telescope,* Jul. 1991, p. 103.

• Schaefer, B. "Solar Eclipses that Changed the World" in *Sky & Telescope,* May 1994, p. 36. Some very interesting historical anecdotes involving eclipses of the Sun.

Silverman, S. & Mullen, G. "Eclipses: A

Literature of Misadventures" in *Natural History*, Jun/Jul. 1972.

Whiteman, M. "Eclipse Prediction on Your Computer" in *Astronomy*, Nov. 1986, p. 67.

The Dec. 1991 issue of *Sky & Telescope* has many reports from the July 1991 total eclipse of the Sun, which was visible from both Hawaii and Mexico.

Articles on Lunar Eclipses

Dyer, A. & Talcott, R. "Lunar Eclipse Photo Tips" in *Astronomy*, Dec. 1992, p. 77.

Olson, D. "Columbus and an Eclipse of the Moon" in *Sky & Telescope*, Oct. 1992, p. 437.

O'Meara, S. "Strange Lunar Eclipses" in *Sky & Telescope*, Dec. 1992, p. 687.

Schaefer, B. "Lunar Eclipses that Changed the World" in *Sky & Telescope*, Dec. 1992, p. 639.

SELECTED READINGS FOR STUDENTS

Grades 4-6

Asimov, I. *The Sun*. 1988, Gareth Stevens. Has a brief section on eclipses.

Pasachoff, D. & J. "Dazzled by Solar Eclipses" in *Odyssey*, 1993, issue 6, p. 14.

Walz-Chojnacki, G. "See the Eclipse — Just Don't Look At It" in *Odyssey*, 1991, issue 7, p. 10 and 12. Eclipse explanations and observing hints, with good drawings.

Grades 7-9

Davis, D. & Levasseur-Regourd, A. *Our Sun and the Inner Planets*. 1989, Facts on File. Has a nice section on eclipses.

SELECTED AUDIOVISUAL MATERIALS

EclipseMaster (IBM Software from Zephyr Services) Calculates aspects of eclipses.

Eclipse of the Century (58-min video, episode of the NOVA public TV series, from PBS Video or the Astronomical Society of the Pacific) Good coverage of the July 1991 eclipse of the Sun, from both the science and the tourist perspective.

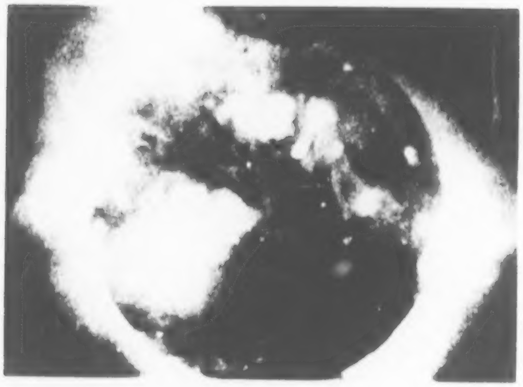
Glorious Eclipses (1992 slides, Sky Publishing or the Astronomical Society of the Pacific) 19 slides plus explanatory booklet.

The Great Eclipse (54-min video from Sky Publishing) Human interest documentary about the July 1991 eclipse as seen from Mexico.

TotalEclipse (IBM software from Zephyr Services) Sophisticated package for calculating and displaying on Earth maps the path and characteristics of lunar and solar eclipses.

B

SUN AND SEASONS

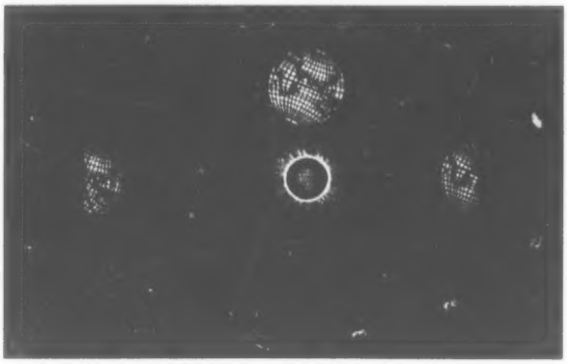


ACTIVITIES INCLUDED IN SUN AND SEASONS

ACTIVITY				ESTIMATED GRADE LEVEL								
Grades	1	2	3	4	5	6	7	8	9	10	11	12
B-1. The Sun Students learn about the properties and functions of the Sun.			□	■	■	□						
B-2. Observing the Sun Safely How to use binoculars, a telescope or a mirror to view the Sun safely.				■	■	■	■	■	■	□	□	□
B-3. Observing Where the Sun Sets Students observe and record, over a long period of time, where the Sun sets.		■	■	■	■	■	■	■	■	■	■	■
B-4. Sunrises at Stonehenge Students plot where the sunrise occurs at Stonehenge in the year 2000.				□	□	■	■	■	■	□	□	□
B-5. The Reasons for Seasons Students use a ball to simulate how the tilt of the Earth's axis affects the length of day and the amount of energy received by the ground.				□	□	■	■	■	■	■	□	□
B-6. Making Pictures of Motion Using a flashlight and toothpick, students create a shadow and measure its length as the position of the light changes.						■	■	■	■	□	□	□
B-7. Making a Sun Clock Students make a paper sundial and use it to connect the concept of time with the motion of the Sun across the sky.					□	■	■	■	□	□	□	
B-8. Plotting the Apparent Daily Motion of the Sun By placing marks on a transparent plastic hemisphere, students record the path of the Sun across the sky.							□	□	■	■	■	■
B-9. Solar Motion Detector Students make a device which models the daily path of the Sun across the sky.							□	■	■	■	□	□
B-10. Modeling the Reasons for the Seasons Students measure the changing apparent size of the Sun during the year to discover that the changing Earth-Sun distance does not account for the seasons.									□	■	■	■

■ - Grade levels recommended by authors □ - Can be extended to these grade levels.

About the Activities:
Sun and Seasons



KEY IDEAS IN "SUN AND SEASONS"

- Ancient peoples recognized that the Sun was related to the seasons, since it climbed higher in the sky and stayed up longer in the summer than in the winter.
- The *Benchmarks for Science Literacy* recognizes that "The cause of the seasons is a subtle combination of global and orbital geometry and of the effects of radiation at different angles. Students can learn part of the story at this [6-8] grade level, but a complete picture cannot be expected until later."
- Activities in this section invite students to observe how the rising and setting points of the Sun, as well as its daily path through the sky, change throughout the year. These observations explain seasons from the Earth point of view.
- Other activities help the students understand the seasons from the space point of view by visualizing the Earth's tilt with respect to its orbit around the Sun.

The Sun is our nearest star, so we know more about it than any other. But long before it was understood that the Sun is a star, people recognized its importance to life on Earth. Many worshipped it as a god, and kept track of its movements. Ancient peoples recognized that the Sun was related to the seasons, since it climbed higher in the sky and stayed up longer in the summer than in the winter. The Sun's movements laid the basis for our twenty-four hour day, our year of 365-1/4 days, and the division of the year into four seasons marked by solstices and equinoxes.

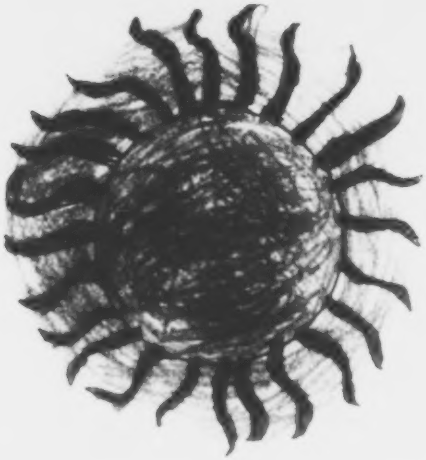
The *Benchmarks for Science Literacy* recommends that study of the Sun begin at the earliest grade levels, when the students are able to observe that "The Sun can be seen only in the daytime, but the Moon can be seen sometimes at night and sometimes during the day." (*Benchmarks*, page 62.) In the elementary years students can observe the Sun safely by projection, and use models to learn about the relative sizes and movements of the Earth, Sun, and planets; but a full understanding of the seasons is more difficult: "The cause of the seasons is a subtle combination of global and orbital geometry and of the effects of radiation at different angles. Students can learn part of the story at this [6-8] grade level, but a complete picture cannot be expected until later [in grades 9-12]." (*Benchmarks*, page 68.)

Activities 1 and 2 are concerned with observing the Sun as an object. Since looking directly at the Sun can cause retinal damage, safety is emphasized. Activities 3-4 invite the students to observe and record sunrises and sunsets, and to realize that in fact the Sun does not rise and set due east and west, but the rising and setting points vary in a predictable way throughout the year. The Sun reaches the extreme northerly and southerly horizon points on the winter and summer solstices.

Activities 6-9 are concerned with the Sun's path through the sky during the day, and how this path changes during the year. Through these activities students are introduced to observable phenomena that are related to the seasons: the Sun's path takes it higher and higher in the sky as it becomes summer, and the Sun spends more hours above the horizon during the summer than during winter. These observations allow the students to understand the causes of the seasons from the Earth point of view.

Finally, Activities 5 and 10 invite the students to take up a vantage point in space, and visualize the Earth's tilt with respect to its orbit around the Sun. Through concrete models they observe how the Earth's tilt brings about the change in the Sun's movement during the year, causing the seasons.

BACKGROUND:
SUN AND SEASONS



Our Sun is the nearest star to Earth. It is a typical star, a huge ball of gas so large that slightly more than one hundred Earths could fit across its equator. It only seems so imposing because it is so very close to us compared to the rest of the stars in the night sky. Because of its proximity, we can see things on it that are impossible to see in distant stars. And so, we can learn a lot about stars in general by studying our Sun.

Although astronomers have found that the Sun is actually on the small side for a star, by Earthly standards the Sun is enormous. A million Earth's would fit inside the Sun's volume! And it weighs 300,000 times more than the Earth! The Sun is a huge ball of hot gas, even in its deep, dense core. There is no solid surface anywhere inside. The immense weight of its outer layers compresses the gas in its center to such high temperatures (27 million degrees Fahrenheit!) that hydrogen atoms, which compose most of the gas in the Sun, "fuse" together to form helium atoms. This process of hydrogen fusion releases tremendous amounts of energy; a single hydrogen fusion reaction (in which four hydrogen atoms become one helium atom) releases as much energy as the chemical burning of 20,000 metric tons of coal. One kilogram (2.2 pounds) of fusing hydrogen produces enough energy to raise an average-sized mountain 10 kilometers (six miles) into the air! For the past five billion years, this fusion energy has powered the Sun, making it shine. And it will continue to do so for about another five billion years, at which point it will begin to die (see the section on Stars for more on what will happen to the Sun).

The energy pouring out from the center has transformed the outer, visible layers of the Sun into a seething cauldron of activity, much of it controlled by strong magnetic fields deeper in the Sun. Heated to temperatures of 10,000 degrees Fahrenheit, the gas near the solar surface bubbles up and down like bubbles in boiling water. Dark sunspots occasionally mar the Sun's surface. These solar blemishes appear dark only because they are cooler than the surrounding gas; they are actually quite hot—over 6000 degrees Fahrenheit! They are, on average, large enough to swallow two entire Earths. The number of sunspots varies according to an eleven-year activity cycle; the last maximum occurred about 1990. In addition, occasional eruptions of gas arch high above the solar surface. These prominences can stretch 500,000 kilometers above the Sun, dwarfing the 12,000-kilometer-wide planet Earth. Solar flares are extremely violent gas ejections; a large flare can release as much energy as 10 billion megatons of TNT, more than 100 million times the energy released in the largest earthly hydrogen bombs!

Despite these occasional fireworks, the Sun has an overwhelmingly beneficial effect on Earth. It provides us with warmth, light and energy. It nourishes our food, and governs our lives with the daily cycle of night and day. Ancient peoples were very in tune with the daily and yearly cycles of the motion of the Sun, although they didn't understand their causes. They thought the Earth stood still and the Sun moved around us. Today, we know it's the other way around. The Sun appears to rise in the east and set in the west each day because of the rotation of the Earth on its axis. And, as Earth orbits around the Sun, taking a year to complete one revolution, the Sun appears to move slowly eastward each day relative to the background stars. Of course, we can't see stars during the day because the Sun shines too brightly, but we can see changes in which constellations are visible at different times of the year, a consequence of the Earth's motion around the Sun. The apparent path of the Sun through the sky each year is called the ecliptic. It is really the projection of the Earth's orbit onto the sky.

As the Earth moves around the Sun, we experience different seasons. Many people think seasons come about because of variations in the distance of the Earth from the Sun; when closer, it's warmer. But, actually, the Earth's orbit is very nearly circular; over the course of a year, the distance between the Earth and Sun varies by less than a few percent, not enough to account for any seasonal temperature variations. Nor could this explain why Australia's seasons are opposite to those in North America.

The seasons are actually caused by the tilt (23.5°) of the Earth's axis of rotation with respect to the plane of its orbit around the Sun. Earth holds its rotation axis fixed in space as it moves around the Sun; these days, the axis is pointed toward Polaris, the North Star. Because of this fixed tilt, during summer, the Earth's Northern Hemisphere tips toward the Sun. Six months later, in winter, it tips away from the Sun. As we "lean into" the Sun, it's warmer in summer for two reasons: 1) the summer Sun is visible for more hours each day, providing us with more total heat energy; and 2) the noontime Sun shines almost straight down on us during summer as the Sun climbs high in the sky. This means sunlight strikes the Earth's surface more directly head on, without spreading out very much, increasing the amount of solar energy the ground gets from sunlight and warming it.

During winter, because of the "away-from-the-Sun" tilt of the Northern Hemisphere, the Sun doesn't rise as high in the sky. Coming in at a low angle, the energy from sunlight is spread out over larger areas on the ground, reducing its effectiveness at heating the ground. When combined with shorter hours of daylight, temperatures stay cooler in winter. The seasons are reversed in the Southern Hemisphere; for example, when the Northern Hemisphere tips toward the Sun and is in summer, the Southern half of the Earth tilts away from the Sun and experiences winter.

Solar energy makes life possible on Earth. It drives photosynthesis in plants, which gives us the oxygen we breathe as well as food to eat. Our atmosphere holds solar heat in, providing us with a hospitable climate in which to live. Without the Sun, we probably wouldn't be here. And yet we take the nearest star for granted, secure in the knowledge that tomorrow morning, when we wake up, it will be there, lighting up our lives.

THE SUN

ACTIVITY B-1

GRADE LEVEL: 4-5

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What's This Activity About?

Thousands of years ago, people around the world believed that our Sun was a god, and just hundreds of years ago, our local star was thought of as a giant celestial bonfire. This activity is a nice introduction to the Sun for earlier grades, and it does a good job of illustrating the process of scientific inquiry. Students learn about the Sun's size (scaled to the Earth), its distance, its temperature, composition, and energy output.

What Will Students Do?

Students start by observing a candle and discuss what properties it shares with our Sun. Students then do a scaling activity to dramatically demonstrate the difference in sizes between the Sun and Earth. Then, students make a mini-solar "oven" and discuss how people use solar energy.

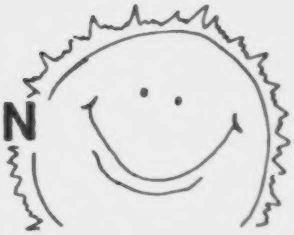
Tips and Suggestions

- Asking students what the Sun might be, and what properties it has, is an excellent way to illustrate how the process of science works—start with observations and infer or deduce conclusions based on those observations.
- Encourage students to consider why other "suns" are so faint in comparison to our local star.
- Although our Sun is not like a candle, the comparison as sources of heat and light is still appropriate for earlier grades. You can reinforce the difference between the Sun and a candle by asking students to consider how much time candles can last, compared with the time we know our Sun has existed.
- Note the typographic error on page 9. The Earth is about 100 Sun diameters away from the "Sun."

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Sizes of stars and planets Stellar energy	Comparing Measuring	Energy Scale Models and Simulations

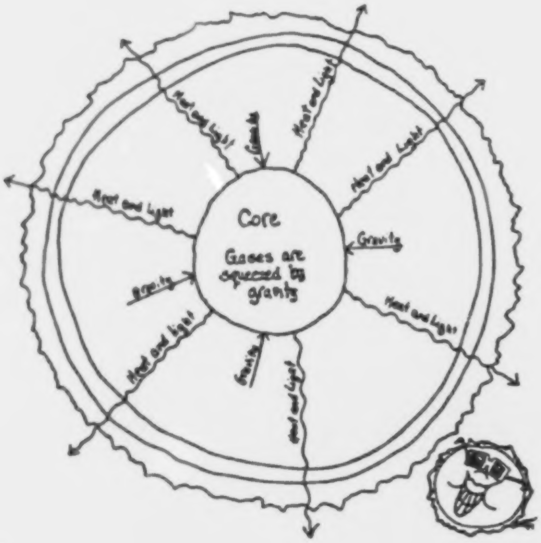
SUN



Our sun, a medium-sized star, is a huge globe of glowing gases. The reason the sun is such an impressive star to us is that it is much closer to us than other stars. It is only about 93 million miles away.

Hydrogen and helium are the main ingredients of the sun. The center of the sun is its "nuclear reactor" which produces energy by converting hydrogen to helium. The released energy rises to the surface after many years and radiates into space. This solar energy is our sunshine. Only a small part of the sun's total radiation reaches the earth. Its travel time from the sun is 8 1/2 minutes.

Nothing is more important to us on earth than the sun. Without the sun's heat and light, our earth would be a lifeless ball of ice-coated rock. The sun gives energy to the growing green plants that provide the food and oxygen for life on earth. We have long recognized the importance of the sun and watched it. Early man worshipped the sun. Scientists have studied the sun with telescopes for 200 years analyzing the light and heat.


Heat and light
Gravity
Heat and light
Heat and Light
Heat and light
Core
Gases are squeezed by gravity
Gravity
gravity
Heat and light
Heat and light
Gravity
Heat and light
Heat and light

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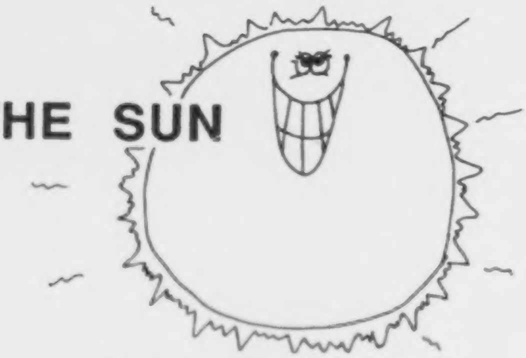
THE SUN



TOPIC

Sun

KEY CONCEPTS

The sun is made of hot glowing gases. It is far from earth. The sun is much larger than earth. The sun is the source of all our energy.

MATERIALS

Kit	Classroom
Candle	Yellow butcher paper
The Sun Book	String and chalk (to draw circle)
Matches	
Tape measure	

BACKGROUND INFORMATION

Our sun, although huge to us, is just a medium-sized star. Its diameter is 109 times bigger than that of the earth, and it is 93 million miles away. Stars are composed of hot gases.

Scientists believe that the sun was formed from a huge mass of hydrogen and helium gas. Gravity compressed the gases causing the temperature to rise. When it got hot enough a thermonuclear reaction took place, and the sun began to glow. It is about 4.5 billion years old and will continue to burn for about that long.

The sun releases enormous amounts of energy in the form of heat and light. The earth receives only about one two-billionth of the total energy released by the sun.

PROCEDURE

1. Light a candle. Ask the children to make observations (candle gives off light and heat, has a flame, has colors, etc.) Ask them to think about the sun. How is the candle like the sun? (gives off light, heat, etc.)

2. Explain to the students that the sun consists of hot glowing gases. It is a sphere and is much larger than earth. We can see only the outer layer of the sun. But deep in the center, gravity is squeezing the hydrogen gas together so hard that it creates explosions which release huge amounts of heat and light. These energies are passed to the surface of the sun and radiate out into space in all directions. Light energy travels across space to earth. When it strikes the earth, the energy heats the land.

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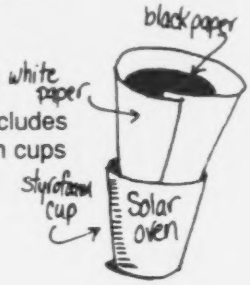
3. Read The Sun by Seymour Simon. Ask the students why we need the sun and how we use the energy from the sun, e.g., light, heat, needed to grow plants (beginning of food cycle); controls the water cycle, the reason for winds and ocean currents. Record their ideas on a chart. Add to the chart as they learn more about the sun. The sheet "Why do We Need the Sun?" is provided as a recording sheet or for a transparency for class recording.

4. Construct models of the sun and earth to show the students. It is important to show the class an accurate model of the sun and earth both in size and distance. The diameter of the sun is 109 times that of the earth. A paper model can be made. Draw a circle with a .5 cm diameter for the earth (.5 x 109 = 54.5) and a circle with a 55 cm diameter for the sun. Other models are a large beach ball (sun) and a pea (earth) or a large yellow ball (sun) and the head of a pin (earth). If you want to add the moon, remember that its diameter is only 1/4 of earth's diameter. "How Far to the Sun?" can be used as a student recording sheet or as class directions on the overhead projector.

5. If the sun is so hot and so big, why don't we burn up? The sun is 93 million miles from earth. Take the class outside with their models of the earth and sun. The earth is about 100 sun diameters away from the earth. Begin at the model of the earth and use your model of the sun to measure out the distance of 100 sun diameters. If you are using the paper models, then the earth will be (100 x 55 cm = 5,500 cm) 55 meters away from the sun. The distance and size is very impressive to students. It is an accurate model that is sure to stay with them through later studies of Space Science.

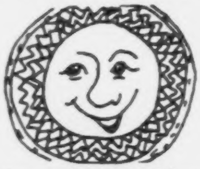
EXTENSION

Use the energy from the sun to cook. The "Mini-Solar Oven" sheet includes directions for constructing simple solar ovens. Collect used styrofoam cups from meetings.



SUBJECT INTEGRATION

Art



The sun and symbols of the sun have been art images over history. Create your own sun design. Have the students decorate circles of butcher paper. Staple two circles together, stuff, and hang above or beside their desks.

EVALUATION

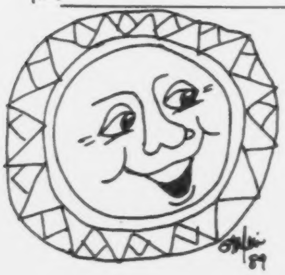
Have students write about their reactions to "How Far to the Sun?". They should write about their understanding of the difference in size of the earth and sun.

Astronomer: ____________________

Why do We Need the Sun?

Brainstorm a list of all the ways we use energy from the sun.

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________
6. ______________________________
7. ______________________________
8. ______________________________
9. ______________________________
10. ______________________________
11. ______________________________
12. ______________________________



Use the back if you have more ideas. Ask a friend, a parent, and other teachers to help add to your list.

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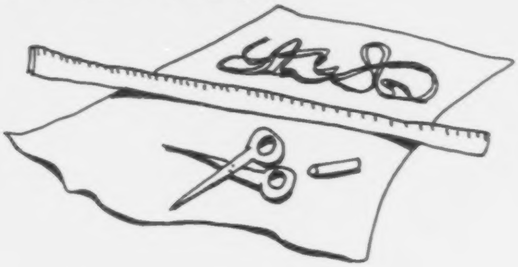
How Far to the Sun?

You will need: paper
scissors
meter stick
string, chalk

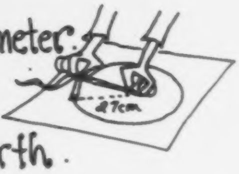


Do This:

1. Make a paper model of the sun and earth.

   Earth - Cut a paper circle this big. Earth (.5cm)

   Sun - Cut a paper circle 55cm in diameter. Use string and chalk to draw it.



2. Estimate how far the sun is from the earth. Place the two models that far apart.

   Measure the distance between

   My guess: ____________

3. The earth is 93,000,000 miles from the sun. Start at the earth and walk the model of the sun 100 suns away.

   Measure the distance between.

   My measurement: ____________

4. Glue your earth to the sun. Wow!

5. If the sun is so much larger than earth, why does it look so small?

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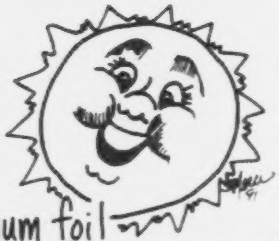
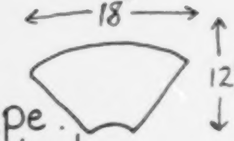
Mini-Solar Oven



You will need: (makes 1 oven)

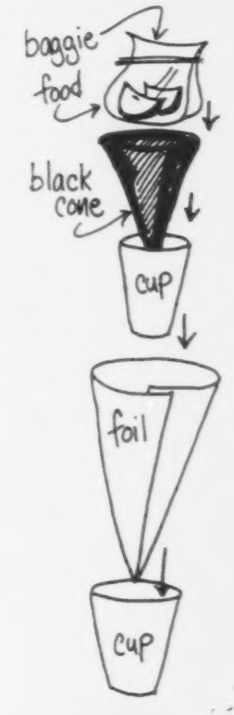
- 1 - 12X18 white paper
- 1 - 6x9 black paper
- aluminum foil
- patterns for cones (tag)
- 2 styrofoam cups

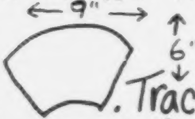
Do This:



1. Use tagboard to make a pattern of this shape. Trace the tag pattern on white 12"x18" paper and cut out.

2. Cover both sides of the white shape with aluminum foil. Roll into a cone shape and put into the cup. Put the second cup inside. Push down all the way to hold the foil in place. This makes the oven's base.

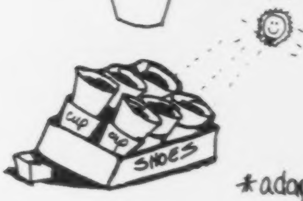




3. Make another tag shape. Trace and cut out of black paper. Make a cone shape and put inside the second cup.

4. The solar oven is now ready to cook in the sunshine. Put food inside a plastic baggie and place inside the oven.

5. Place 4-6 ovens into a shoebox. Tilt to catch the most direct rays of the sun. Turn box to keep the sun shining inside the ovens.



6. Things to cook include: apple slices with raisins and cinnamon, sliced hot dogs, or vegetables with butter.

*adapted from Student Solar Oven by Jo Anne Bottini, "The Pocket Book"

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OBSERVING THE SUN SAFELY

ACTIVITY B-2

GRADE LEVEL: 4-9

Source: Copyright ©1993 by the Astronomical Society of the Pacific. This activity was created by Professor John R. Percy, Division of Sciences, Erindale Campus, University of Toronto, Mississauga, Ontario, Canada L5L 1C6.

What's This Activity About?

Students may believe that astronomy can only be done at night, but this activity is a fun way to show that we can perform experiments in sunlight, too. This activity describes how to view the Sun's visible disk safely by projecting its image, instead of by direct observation. Two methods for collecting and focusing sunlight are described, using binoculars or small telescopes. Both methods are safe for all ages if instuctions are followed.

What Will Students Do?

Students (or an adult) use binoculars or a small telescope to collect sunlight, and project it safely on to paper, where they can detect sunspots. Alternately, students can use a small mirror placed outside the classroom to reflect sunlight into the darkened room, onto a large white page.

Tips and Suggestions

- Ask students to count sunspots and to draw their approximate location on the Sun's surface. Make a series of observations over several weeks to see how the sunspots move. Galileo performed a similar experiment to show that the Sun rotates about its own axis.
- Note that the projection method using a mirror can produce a rather dim image if the mirror is not of high quality, or the classroom

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Creating an image Safety in experiments	Observing Using Instruments Recording	Structure

OBSERVING THE SUN SAFELY

by John R. Percy
University of Toronto

We must begin with an important warning: never look directly at the Sun, especially when using binoculars or a telescope. Direct sunlight can cause **PERMANENT EYE DAMAGE** in seconds, without the victim being aware of it until it is too late.

Although some telescopes are equipped with Sun filters, many of these are not reliable, and should not be used unless you are *absolutely* sure of what you are doing. The only reliable filters are some (but not all) which fit over the front of the telescope, and reflect away most of the light. For safe direct viewing of the Sun, #14 welder's glass can be used, or a proprietary material known as Solar Skreen (Roger W. Tuthill, Inc., 11 Tanglewood Lane, Mountainside NJ 07092).

The best way to view the Sun with binoculars or a telescope is by *projection*—looking at an image of the Sun rather than at the Sun itself. Instructions for doing this are given below.

We should note that some school officials feel that all viewing of the Sun should be forbidden. Even though there are safe ways to view the Sun, there is always a chance that some student will not take the necessary precautions, or will disobey instructions, and an accident will occur. The projection methods described below are quite safe, however, and the number of astronomy-related school accidents is far less than the number encountered in other science subjects!

VIEWING THE SUN BY PROJECTION

This method is relatively safe and, with it, many people can view the Sun at once. You will need a pair of binoculars or a small telescope, a piece of plain cardboard about 30 centimeters square for the "collar", and a second piece of white cardboard (or paper) at least 10 centimeters square for the screen. If you use a telescope, you should mount it on a tripod. If you use binoculars, you can hold them in your hand, but it is much more convenient (and you will have a steadier image) if you improvise some sort of stand or tripod to hold them.

This demonstration can be done at any time of the day when it is clear and when your class has access to direct sunlight.

Dr. Percy is a professor of astronomy at the University of Toronto in Canada and one of the world's leaders in the field of astronomy education.

Method

1. Make a cardboard collar to fit around the front end of the binocular or telescope, as shown in the figure below. This shades the area where the image will be from sunlight, and (in the case of binoculars) will cover the lens which you are not using.
2. Focus the binocular or telescope on infinity by looking at a distant object (not the Sun!) in the normal way. (If you are using a telescope, use a low-magnification eyepiece.)
3. Point the binoculars or telescope at the Sun (DO *NOT* LOOK THROUGH THE INSTRUMENT TO DO THIS!), as shown in the figure, and adjust the direction of pointing until the image of the Sun appears on the screen. (This may take a minute or two. One useful trick is to watch the shadow of the binoculars or telescope tube: if pointed directly toward the Sun, then the sides of the tube will cast no shadows, and the instrument's shadow will be as small as it can be.)
4. Move the screen toward or away from the eyepiece until the image of the Sun fits neatly in the middle, and adjust its tilt until the Sun's image is circular.
5. Jiggle the binoculars or telescope very slightly. Any specks on the image of the Sun which do not jiggle along with the image when you do this are specks in the binoculars or telescope (or smudges on the screen), and not spots on the Sun itself.

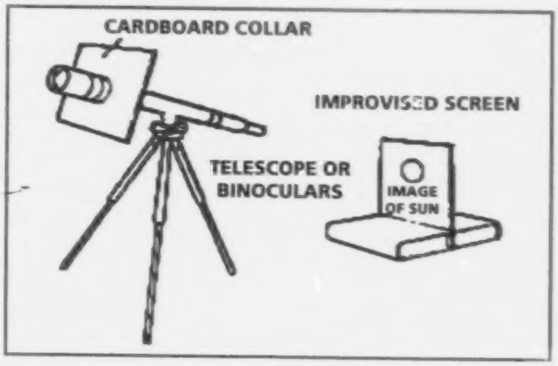
NOTE:

Do not use binoculars whose front lenses are 50 millimeters across or wider. (Binoculars usually are described by a pair of numbers separated by an "x," such as "7 x 35" or "7 x 50", the number to the right of the "x" is the diameter of the front lenses in millimeters.) Big lenses gather a lot of light, and the heat generated by direct sunlight inside large binoculars can damage their complex optics.

Observations

When you and your students examine an image of the Sun, you will notice the following properties:

1. The image is brighter in the middle of the disc than at the edges. This effect is called *limb-darkening*. It occurs because, when we look at the middle of the Sun's disc, we are looking straight down into the hotter part of the Sun. At the edges of the disc, we look more obliquely, and see only the cooler, less bright gases, higher in the Sun's atmosphere.



2. The image moves slowly across the screen. This is due to the east-to-west motion of the Sun in the sky, caused by the rotation of the Earth. The direction of motion of the image therefore tells you which direction on the screen (and on the Sun's image) is west.
3. There may be small dark spots on the image. These are called sunspots and are regions in the outer layers of the Sun which are cooler and therefore not as bright as their surroundings. In sunspots, the Sun's magnetic field is exceptionally strong, and astronomers suspect that this is connected to their being darker than the material around them. Sunspots, when examined closely with a telescope, are seen to be very complex. They can form within a few days, and may endure and evolve for weeks or months.

AN ALTERNATE WAY TO PROJECT AN IMAGE OF THE SUN

This method produces an image which is a bit fuzzy, but good enough to show large sunspots, and it is particularly suitable for observing a partial eclipse of the Sun. It is very safe, and can be used to show an image of the Sun to an entire class.

You will need a small pocket mirror or hand mirror, a piece of plain cardboard to fit over the mirror (or some tape to cover it), and a piece of white cardboard or paper to use as a screen.

Method

1. Cut the plain cardboard or paper so it fits over the mirror.
2. Cut or punch a very small hole, about five millimeters in size, in the middle of the plain cardboard. (You could also use tape to cover all but a small portion of the surface of the mirror.)
3. Put the mirror on a window sill in the sunlight so that it catches the rays from the Sun. Turn the room lights off and draw the window blinds so that as little as possible of the room other than the mirror is in sunlight.
4. Reflect the sunlight onto a wall of the darkened room.
5. Put the white cardboard or paper on the wall at this point, so you can use it as a screen to display the image of the Sun.

Observations

1. You will notice that the image of the Sun is round (unless an eclipse is in progress), even if the hole which you cut or punched in the plain cardboard or paper was square!
2. You can also demonstrate that the size of the image of the Sun is proportional to the distance of the screen from the mirror. The larger the distance, the larger (and fainter) the image. In a more advanced class, you might want to develop an explanation for these two observations.

If you do not have a classroom in which there is a sunlit window, you can do the activity outdoors. Find a place where you can catch the sunlight with your mirror, and can reflect it onto a shaded wall. (Better still, reflect it into a darkened classroom.) Again, you can use a sheet of white paper or cardboard as a screen. It takes a few minutes to discover the best arrangement for the mirror and the screen, but once you have done so, it is easy to set up the demonstration again on any following day.

OBSERVING WHERE THE SUN SETS

ACTIVITY B-3

GRADE LEVEL: 2-9+

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What's This Activity About?

Observing the motions and changes in the Sun and stars is the foundation for relating the science of astronomy to our lives and to the passage of time. Encourage your students to observe their world and how it changes with this simple long-term activity. It is an excellent lead-in to learning about the seasons. It can also be linked to social studies, as students learn how different cultures around the world have used the Sun's rising and setting positions on the horizon as a calendar for agriculture, religion, or migration.

What Will Students Do?

Students are to observe and record where on their local horizon the Sun sets over a long period of time—the longer the better. Their record becomes a horizon calendar, similar to those created by societies across the Americas, Europe, and Africa.

Tips and Suggestions

- Creating a complete horizon calendar would take one year, but this activity is still useful even if carried out over just 2-3 months because students can see that the sunset position does indeed move. The sunset position will change the fastest during autumn and spring, and less rapidly around the winter and summer solstices.
- Create a horizon calendar for the class on a wall. Assign two students each week to watch the sunset and bring back their observations to the class. (They can check their data with each other, and if in agreement, plot the position for that week.) Attach other information to the chart (the school calendar, holidays, etc.). Students will begin to associate the sunset position changes with time.
- If you use a compass to find North, remember that the compass points to *magnetic* North, not *geographic* North. Depending on your latitude and longitude, the magnetic deflection from true geographic north varies.
- Another method is to make observations from one special location and to establish proper compass points to help the observers. You can use Polaris to locate geographic North.
- This is a wonderful experiment to be shared with the family. Ask parents to help with the observations each week.

What Will Students Learn?

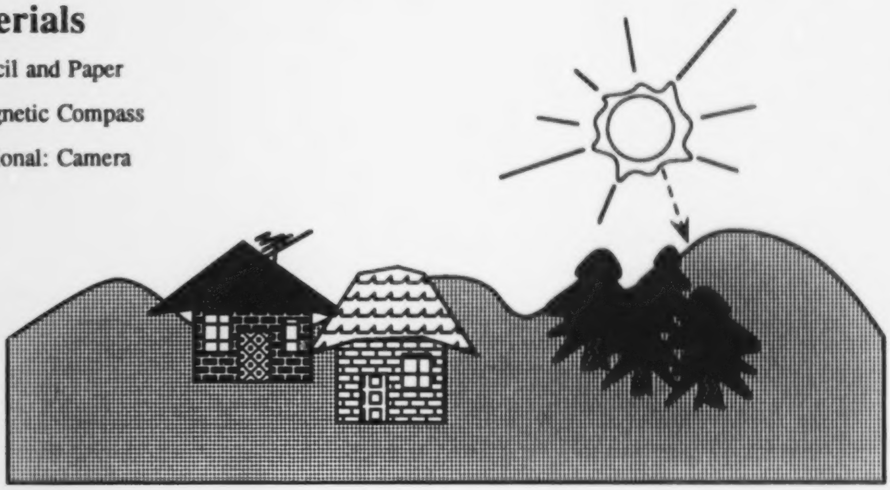
Concepts	Inquiry Skills	Big Ideas
The revolution of the Earth about the Sun Compass directions	Observing Systematically Visualizing	Patterns of Change

Observing Where the Sun Sets

This activity is for students to do at home. When they complete it, they will have created a horizon Sun calendar much like ones that were used in many Native American tribes.

Materials

- ☐ Pencil and Paper
- ☐ Magnetic Compass
- ☐ Optional: Camera



What to Do at Home

1. Select a position where you can observe the setting Sun. Note where on the horizon the sun sets on a given night. Make a drawing or take a picture of the horizon in that general area.

2. Using a magnetic compass, mark the compass directions northwest, west, and southwest on your picture or drawing.

3. Once or twice a week for the next month, mark the location where the Sun sets for each clear day, and record the date and time of the sunset. **Be sure to always make your observations from the same spot.**

4. Discuss results in class. ***Does the sun set further to the south, further to the north, or in the same place on later days as compared with the first day?***

Going Further

1. Observe the same star set each night for a period of about a week. **Be sure to always observe from the same spot. *Does its setting point change in the same way that the Sun's does?***

2. Try to guess where the Sun would set three months later. How about six months later? Mark those guesses on your horizon picture (in pencil). Check your guesses after the months have gone by.

3. Could you devise a way to make a calendar using the information in this activity?

4. Make the same type of observations of the rising point of the Sun.

5. Can you find any relationship between the location of sunset and the time of sunset?

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SUNRISES AT STONEHENGE

ACTIVITY B-4

GRADE LEVEL: 6-9

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What's This Activity About?

Examples of horizon astronomy—using sunrise and sunset positions as a calendar—exist in the history of many cultures. One of the best known examples is Stonehenge, the ancient collection of monoliths in southern England, now believed to have been built and used over many centuries by perhaps three different groups of people. This activity simulates a detailed study of sunrise positions at Stonehenge over a year.

What Will Students Do?

Students will plot where the Sun rises as observed at Stonehenge for each month of the year 2000. They will measure *azimuth*, defined as the angle around the horizon from due north. Students then analyze the azimuth plot to see when the Sun rises furthest north and south, and when the sunrise azimuth changes most from month to month.

Tips and Suggestions

- This activity was originally designed as part of a planetarium program which simulated the giant stones of Stonehenge, giving students the impression of actually being at the site but it can also be done in the classroom.
- This activity can be used as a simple illustration of horizon astronomy, but it will be more significant if the history of Stonehenge is discussed as well.
- If students do study Stonehenge, they can create physical models of the site, and even use large pieces of butcher paper placed around the classroom walls to simulate the monoliths.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Changing position of the Sun over the year	Graphing	Patterns of Change
Azimuth	Inferring	Models

In Class

1. Let's pretend that we are near Stonehenge in Southern England. We have a clear view of the horizon and can watch the Sun rise every day of the year.

If the students have already seen the Stonehenge planetarium program, ask them to recall what they learned about how the position of sunrise changes throughout the year:

What's the longest day of the year? (about June 21, the Summer Solstice.)

On the Summer Solstice, does the Sun rise to the north or the south of East? (The Sun rises to the north of East in the summer.)

What's the shortest day of the year? (about December 21, the Winter Solstice.)

On the Winter Solstice, does the Sun rise to the north or south of East? (The Sun rises to the south of East in the winter.)

2. We are going to make a chart that will show how the sunrise postions change throughout the year.

Hand out a blank sunrise chart to each student. (Do not hand out the tables yet.) Point out the words "Azimuth of Sunrise" along the bottom. Review concepts from Azimuth and Horizons *activity (p. 28):*

What does azimuth mean? (Azimuth means the direction in degrees, as marked on a compass.)

What is the azimuth of North? (0°) ***East?*** (90°) ***South?*** (180°)

If the Sun were to rise exactly in the Northeast (halfway between North and East), what would the azimuth of sunrise be? (45°)

3. ***How far to the North will the Sun rise on the Summer Solstice, as seen from Stonehenge?***

Ask a few students to share their guesses with the rest of the class. Then, show the students how to indicate their guesses on the chart. Find the month of June along the left, and the azimuth of the guess on the chart. Place a pencil dot in the box that indicates both the month of June and azimuth of sunrise. For example, if they think that the builders of Stonehenge will see sunrise exactly in the Northeast on June 21, they should put a dot in the box to the right of June, and above 45°.

4. ***Place a pencil dot showing the azimuth of sunrise for each of these four important dates:***

Summer Solstice, about June 21
Winter Solstice, about December 21
Spring Equinox, about March 21
Fall Equinox, about September 21

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5. ***Use your pencils to join the four pencil dots with a smooth curve, showing how you think the sunrise point will change between the four important dates.***

Invite them to share their predictions with their neighbors. Invite some of the students to share their predictions with the whole class.

6. Here is a Table of Sunrise positions at Stonehenge.

Hand out the Table of Sunrise Positions at Stonehenge.

The table shows the actual azimuth of sunrise as we would see it if we made observations at Stonehenge today. ***Use a colored pencil or pen to plot each position on your chart with an "x," and then to use the pen to connect the x's with a smooth line.***

7. ***Compare your paper with your neighbors'.***

Check that they have all plotted the positions of sunrise correctly. Lead a discussion to help the students interepret their results.

How close did your predictions come to the actual observations?

How far to the North did the Sun rise on the Summer Solstice? How far to the South did it rise on the Winter Solstice? Is that more or less than you predicted? (Summer 49°, Winter 128°)

When does the Sun rise due East? (On September 21 and March 21).

Do you think the Sun goes through the same pattern every year? If so, how do we know? (Ancient peoples around the world saw the same pattern of the Sun every year that we still see today!)

The exact dates of solstices and equinoxes changes from year to year, but are always within a day or two of March 21, June 21, September 21, and December 21. This is because the length of the calendar year (365 days) is not exactly the same as the solar year 365.26 days—this is also why we need leap year. For example, in the year 2000, the Summer Solstice will actually occur on June 20, and the Winter Solstice on December 21. You may wish to add that modern measurements indicate that even the azimuth angles change very slightly over the centuries because of slight changes in the tilt of the Earth's axis with respect to its orbit.

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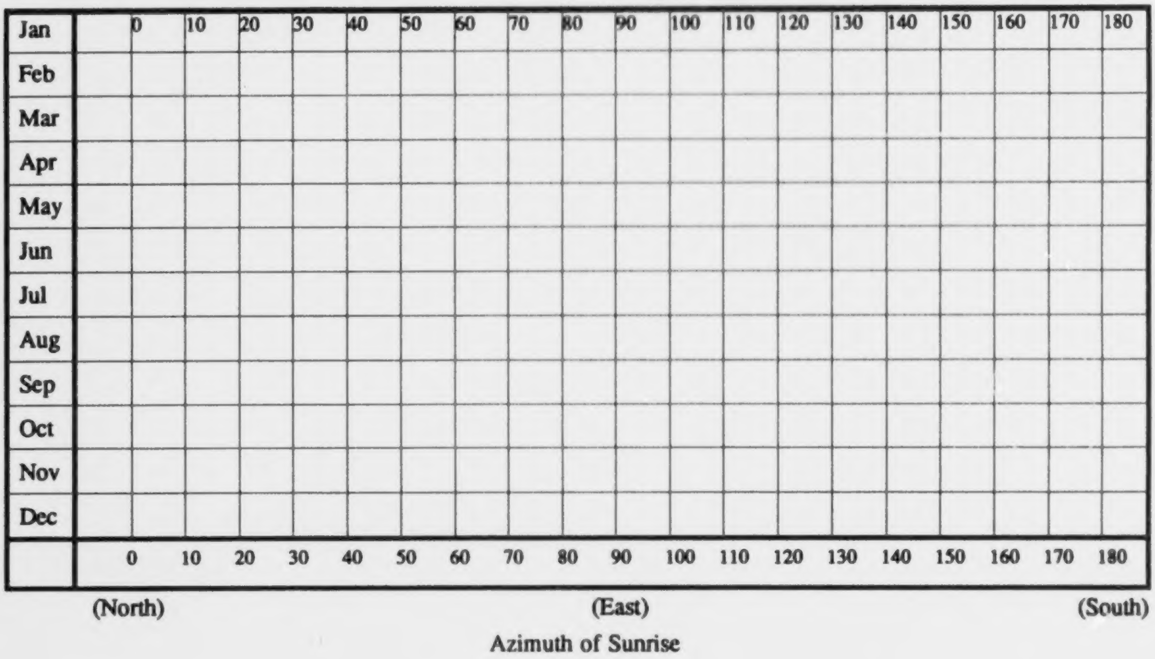
Table of
Sunrise Positions at Stonehenge in the year 2000

Latitude: 51°17' N

Date	Time	Position	Date	Time	Position	Date	Time	Position
01/20	8:03 am	122°	05/20	4:11 am	55°	09/20	5:54 am	87°
02/20	7:14 am	106°	06/20	3:53 am	49°	10/20	6:43 am	106°
03/20	6:11 am	88°	07/20	4:18 am	54°	11/20	7:36 am	121°
04/20	5:03 am	69°	08/20	5:05 am	69°	12/20	8:12 am	128°

Chart of Sunrise Positions (Year:_______ Latitude:________)



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Going Further

1. It is very interesting to explore more precisely the day to day change in the azimuth of sunrise. For this purpose, the table below shows the azimuth of sunrise on two or more successive days for each month of the year. Make a copy of the table for each student. Explain that these tables are more precise because the azimuths are given with degrees *and* minutes (minutes indicated by the symbol " ' "). There are 60 minutes in each degree. After the students have studied the table for a while, ask

During which months does azimuth of sunrise change the most from one day to the next? (March and September)

During which months does the azimuth of sunrise change the least? (June and December)

What are the exact dates of the solstices for the year 2000? (December 21 and June 20)

2. Instead of handing out the sunrise tables, have the students create their own, using a computer with astronomical "planetarium" software that can compute precise sunrise positions. For example, the data compiled on page 45 was generated by the *Voyager* program (from Carina Software, 830 Williams St., San Leandro, CA 94577; 510-352-7328) for Macintosh computers. An appropriate program for IBM-compatible computers is *AstroInfo*, which gives daily Sun and Moon risings and settings, with azimuth angles. It is available from Zephyr Services, 1900 Murray Ave., Dept. A, Pittsburgh, PA 15217; phone 800-533-6666. *NIGHTSKY*, also for IBM-compatibles, is a similar program to Voyager in that it produces star charts as well as tables. It is available from Southwest Astronomy, 4242 Roma NE, Albuquerque, NM 87108. *NS Lito* (a simple version of *NIGHTSKY*) is available as freeware on computer services such as Compuserve.

3. Make a similar sunrise position chart for another year to verify that it is essentially the same shape.

4. The latitude of Stonehenge is 51°17' N. Use a computer program to generate a table of sunrise positions for the latitude of your school.

More Sunrise Positions at Stonehenge in the year 2000

Latitude: 51°17' N

Date	Time	Position	Date	Time	Position	Date	Time	Position
01/20	8:03 am	122°09'	06/19	3:53 am	49°06'	09/22	5:57 am	88°56'
01/21	8:03 am	121°46'	06/20	3:53 am	49°03'	09/23	5:58 am	89°27'
02/20	7:14 am	106°40'	06/21	3:54 am	49°06'	09/24	6:00 am	90°09'
02/21	7:12 am	106°05'	06/22	3:54 am	49°07'	10/20	6:43 am	106°02'
03/18	6:16 am	90°05'	06/23	3:54 am	49°08'	10/21	6:45 am	106°41'
03/19	6:13 am	89°19'	06/24	3:55 am	49°18'	11/20	7:36 am	121°37'
03/20	6:11 am	88°45'	07/20	4:18 am	54°34'	11/21	7:38 am	122°04'
04/20	5:03 am	69°57'	07/21	4:19 am	54°52'	12/19	8:11 am	128°07'
04/21	5:01 am	69°24'	08/20	5:05 am	69°10'	12/20	8:12 am	128°13'
05/20	4:11 am	55°22'	08/21	5:06 am	69°37'	12/21	8:12 am	128°14'
05/21	4:10 am	55°03'	09/20	5:54 am	87°43'	12/22	8:13 am	128°13'
06/18	3:53 am	49°09'	09/21	5:55 am	88°14'	12/23	8:13 am	128°07'
						12/24	8:13 am	128°00'

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THE REASONS FOR SEASONS

ACTIVITY B-5

GRADE LEVEL: 6-10

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What's This Activity About?

Asking students—and most adults—why seasons occur usually elicits the response, "because the Earth is closer to the Sun in summer, and farther away in winter." Dispelling this misconception can be very difficult, but this activity, originally designed for use in a planetarium, will help. Students will see that the length of daylight, and the angle of the Sun in the sky at noon, are factors contributing to seasonal variation. This is a three-part activity.

What Will Students Do?

In the first part of the activity, students observe the height of the Sun and the duration of daylight during each season. In the second part of the activity, students use a Styrofoam ball to simulate the effect of the Earth's tilt on light, shadow, and duration of daylight. In the third part, students make a light angle/area measuring tool to help them see a connection between the angle of sunlight and the amount of energy received on the ground.

Tips and Suggestions

- The first part of the activity is intended for a planetarium where the motion of the Sun during the day and year can be simulated. The rest, beginning on the second page, can be done without a planetarium.
- Even after doing this activity, your students may still believe that seasons result from the Earth's distance from the Sun. Their answers may now include something about tilt, or daylight hours, similar to "the Earth is tilted closer to the Sun in the northern hemisphere in summer, and tilted farther away from the Sun in winter." The table of Earth-Sun distances below shows that our planet is closest to the Sun in January—for *both* hemispheres—and farthest in July. Tilting one hemisphere toward or away from the Sun will change its distance only a thousand miles or so compared with the opposite hemisphere. This distance is insignificant compared with the 6 million km difference between January and July. If distance from the Sun was the major factor, *both* hemispheres would experience summer in January, and winter in July!

Month	Average Earth-Sun Distance
January	147,000,000 km
March	149,000,000 km
June	153,000,000 km
July	153,000,000 km
September	150,000,000 km
December	148,000,000 km

Note that an even more accurate table is included in the cover sheet for activity B-10, "Modeling the Reason for the Seasons."

What Will Students Learn?

Concepts

Seasonal variation
Revolution of the Earth about the Sun
Energy received over an area

Inquiry Skills

Observing Systematically
Visualizing
Recording
Reasoning
Using Instruments

Big Ideas

Patterns of Change
Energy
Systems

ACTIVITY 12: THE REASONS FOR SEASONS

Educational research has shown that understanding why it is warmer and the days are longer in the summer than in the winter is very difficult for students. This activity approaches this subject by having the students observe and record the sun's path through the sky in each of the seasons. At each step they predict what they think they will observe next. They then try to explain why the sun's path varies throughout the year. Finally, they use a model earth ball to visualize how the tilt of the earth's axis causes the variation in the sun's path with the change in seasons.

Grade Levels: 6-9

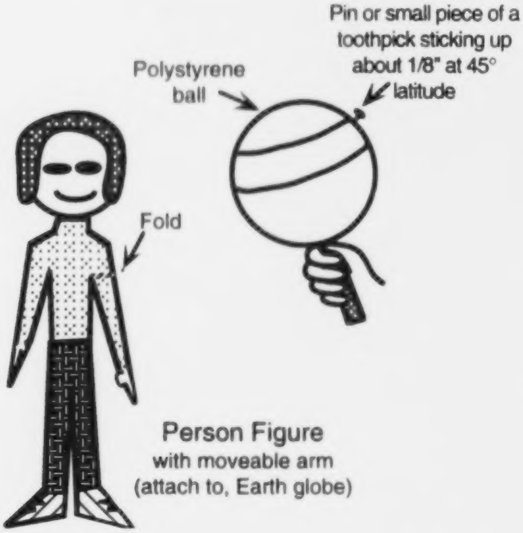
Organization: Individual Task

Reasoning Level: Concrete to Formal

Activity Strategy: Direct Information - Synthesizing

Behavioral Objectives: By the end of the lesson, students should be able to:

1. Describe the apparent daily path of the sun during the four seasons.
2. Explain why the sun's daily path changes during the year.
3. Predict the rising and setting point for the sun for different seasons of the year.
4. Explain why days are longer in the summer and shorter in the winter.


Pin or small piece of a toothpick sticking up about 1/8" at 45° latitude
Polystyrene ball
Fold

Person Figure
with moveable arm
(attach to, Earth globe)

Materials

- Markers to indicate the predicted position of sunrise/sunset on the dome (these could be pieces of cardboard with paper clips on the back for planetariums with coves or sheets of paper hung with masking tape or "Post-It™" style notes)
- A white light in the center of the planetarium to represent the sun, an earth globe that will turn on its axis, and a small paper or toy figure of a person with a movable arm (see illustration) fastened to the earth globe.
- A meridian line projector for measuring the altitude of the sun at noon. In portable planetaria, you can tape marker papers every 10 degrees along the meridian by partly deflating the dome until the zenith can be reached, taping the 90° mark there, and slowly reinflating the dome while putting up markers at 80°, 70°, and so forth along an imagined meridian line towards the southern horizon. Extreme accuracy is not critical.
- North, East, South and West horizon markers (optional: mark every 10° in between those markers). The best pattern is having East and West each be marked 0°, with North and South being 90°.
- Data on the length of day at solstices and equinoxes at your latitude. This may be found in newspapers or observers' handbooks with sunrise and sunset listings.

For each student: a pencil, a copy of the worksheet, a clipboard or other surface to write on, and a 3" polystyrene "earth ball" on a pencil or stick with a pin or piece of toothpick stuck in at about latitude 45° (see diagram).

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Presentation

Engage the students in a discussion about where we see the sun in the sky. Ask if the sun is always at the same height (altitude) above the horizon at noon throughout the year. Ask where the sun rises and sets, and whether or not the direction of sunrise and sunset stays the same every day, or changes throughout the year.

Tell the students that they will be collecting data on the sun's apparent path, including not only the height at noon, but also the length of day and the position of sunrise and sunset throughout the year. Hand out the data sheets. Tell the students that they will have to estimate the sunrise and sunset directions by looking at the N, S, E, W markers on the horizon. In addition, they will need to estimate the sun's position at noon by observing its altitude (in degrees) between the zenith and the horizon (point out the meridian line).

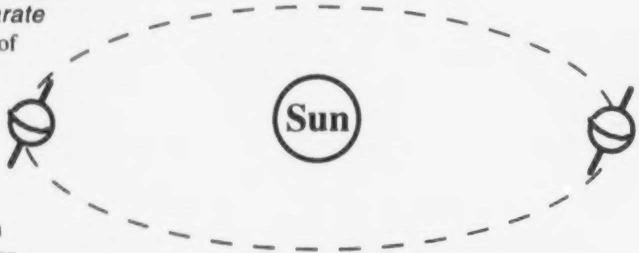
Show the sun's path for the 1st day of summer, fall, winter, and spring (Use the equinoxes and solstices to represent the seasons since the most extreme paths of the sun are observed on those dates.) In each case, have the students **predict sunrise, noon, and sunset** before showing the sun's path on that date. As the sun traverses the sky on each of those dates, the students mark its positions at sunrise, noon, and sunset on their data sheets (Reasons for the Seasons Worksheet). On each date, have student volunteers mark the positions of sunrise and sunset on the cove or side of the dome with a "Post-It™" or other method. ***(Optional: You may extend the chart on the worksheet to include columns for your students to write sunrise and sunset positions, or have the students verbally describe sunrise and sunset positions on a chart on a separate page.)*** After each day, announce the hours of daylight for that day and have the students write that number of hours in the table on their data sheets.

After all the dates are completed, ask the students to draw the sun's path for each date from sunrise to sunset. The path for each season should include a smooth curved line through the sunrise point, noon position, and the sunset point.

Ask the students to study their charts and see if they can suggest a reason to explain these changes. After a discussion of possible explanations, tell the class that a long time ago, astronomers found out that the reason that the sun appears to take such a different path through the sky in different seasons is due to the way the earth is tilted as it travels around the sun. Using the white light as the "sun" and the earth globe, demonstrate that the north pole of the earth always points towards the north star, or Polaris. Holding the globe, walk around the sun, keeping the north pole of the earth pointed towards the north star. Point out that as the earth travels around the sun, the north pole of the earth's axis is tilted towards the sun in the summer, and away from the sun during the winter. Tape the small figure of a person to the globe (at your home latitude) and point out how the person would see the noon sun higher in the summer and lower in the winter. This can be made more apparent if the figure has a movable arm to point toward the sun. In the summer, the arm points high up, while in the winter, the arm points much lower.

Your students can see the model better if you hand each student an "earth ball" with a pin representing a person on it.

1. Have the students tilt their balls towards the sun (summertime), rotate it until the person is experiencing noon (closest to the sun), If the person pointed towards the sun with his arm, would he be pointing high or low in the sky? Do the same for the wintertime sun at noon. Would he be pointing his arm higher or lower?



The earth's axis of rotation is tilted by 23$^1/_2$° with repect to the earth's orbit around the sun.

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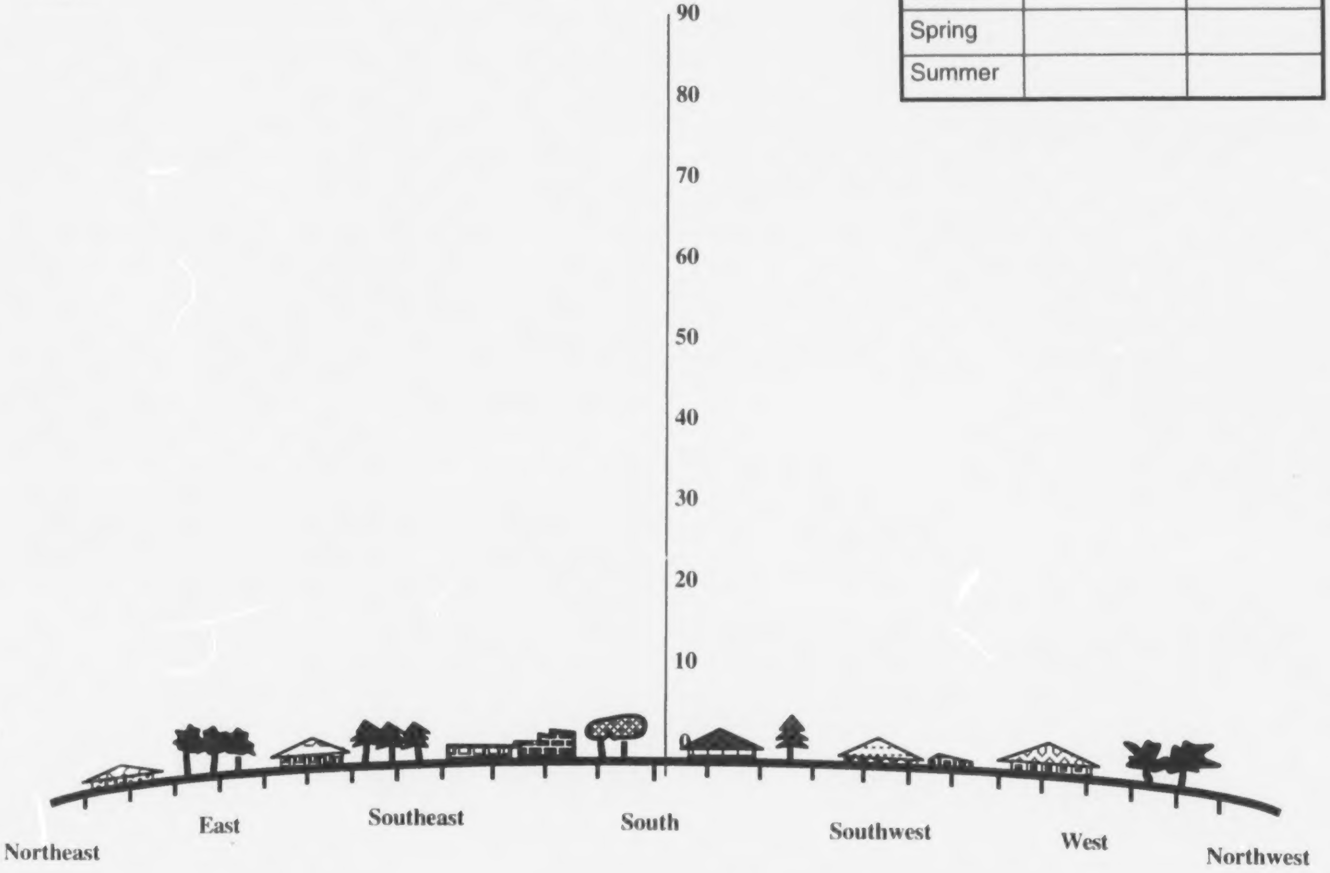
The Reasons for the Seasons—Worksheet

Name ______________________________

Date _____________

SEASON	# HOURS OF DAYLIGHT	NOON POSITION
Autumn		
Winter		
Spring		
Summer		


90
80
70
60
50
40
30
20
10
0
Northeast
East
Southeast
South
Southwest
West
Northwest

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2. Have the students slowly rotate their earths and see the pins move alternately from night to day. They can see that summer nights are shorter than winter nights.
3. Another interesting observation in this model is comparing the length of the shadow of the pin at noon in different seasons.

Finally, have your students use their observations of the sky and earth model to explain why it is hotter in the summer than in the winter, even though the earth is slightly closer to the sun in the winter time. One explanation they may think of is that the days are longer in the summer, allowing the earth to heat up more. That is correct, but it is only part of the story. Another reason is that when the sun is higher in the sky, its light is more concentrated on given areas of earth.

To illustrate, you may try one of the following ideas for a follow-up session.

Follow-Up Activities

1. Prepare a grid to project onto your large earth globe. The grid can be either a grid slide projected through a slide projector, or an overhead projector transparency. An easy way to make a grid is to photocopy a sheet of graph paper onto transparency and either cut a small piece of it to put in a slide mount or use the whole sheet on an overhead projector.

In class, first project the grid onto a flat surface (chalkboard, wall, etc.). Each box represents a unit of light and heat from the sun and all the boxes are equal in size when they start out from the sun. Have the students notice that all the boxes are the same size. If the earth were flat, then all parts of the earth would receive equal amounts of light and heat. Let's see what happens with a round earth. Project the grid onto the earth globe. ***Are all the boxes the same size?*** (No.) ***Where are they the smallest?*** (The parts facing most directly towards the sun.) ***Where are they the largest?*** (Near the poles and parts not facing as directly towards the sun – places where it's early morning or late afternoon.) ***Remembering that each box contains the same amount of heat and light, who would be hotter, a person standing in a region with smaller boxes, or a person standing in a region with larger boxes?*** (The region of smaller boxes would get hotter because more heat is concentrated there, while in regions where there are larger boxes, the heat is being "spread out.")

Put a piece of tape or a push pin at your city's location on the globe. Show the class how the grid boxes shining on the earth change as the earth is tilted towards the sun (summer orientation) and then away from the sun (winter orientation). ***During which season does our city receive more concentrated sunlight?*** (Summer.) That is a reason why it is hotter in the summer than in the winter.

2. With Starlab this can be made into a student activity rather than a demonstration by using the same "earth balls" that were used before. Prepare a grid transparency wrapped into a cylinder to replace the star cylinder. Alternatively, make an opaque cylinder out of manila cardstock and, using a large push pin, make an series of holes around the "equator" of the cylinder. Light from the main star bulb shining through these holes produce standard size "light circles" that will function as units of light as the grid boxes did in Follow-Up activity (1).

Start by having the students catch the grid boxes or light circles on flat pieces of paper. Have them note that the light boxes or circles are all the same size. Then go through the same sequence of questions used in Follow-Up activity (1), except that students can examine their own earth globes in addition to a single large globe that the teacher handles.

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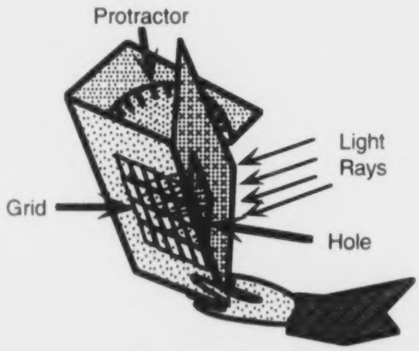
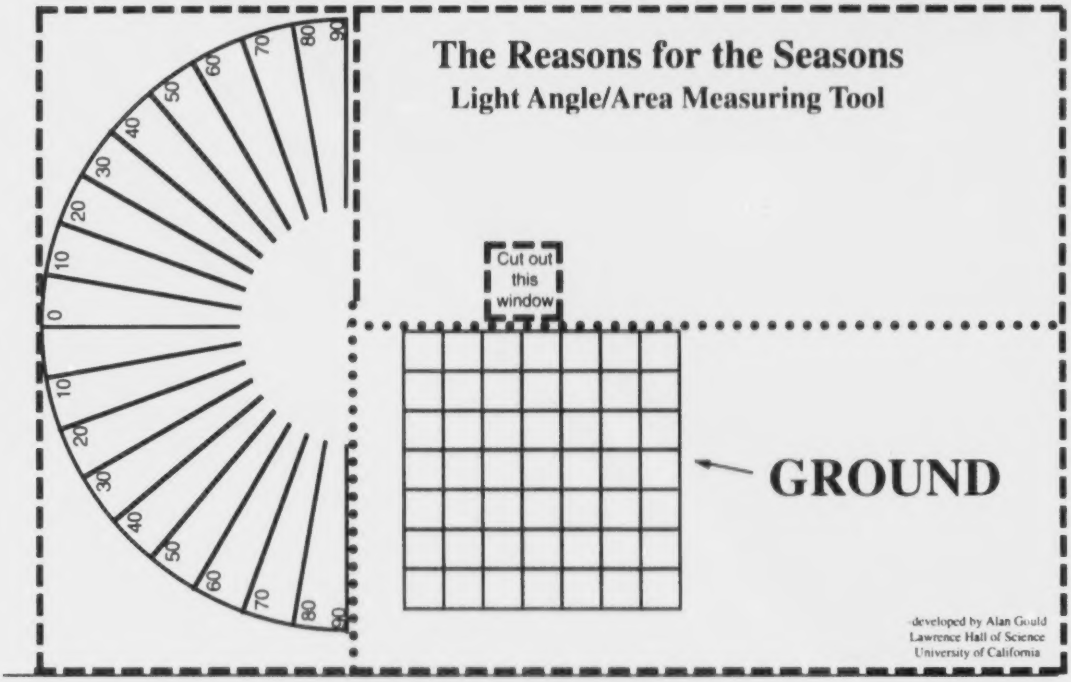
3. Prepare a class set of "Light Angle/Area Measurering Tools" by copying the bottom half of this page onto cardstock and cutting them out as shown (alternatetively, provide your students with scissors and have them make their own). Cut along the dashed lines and fold along the dotted lines.

Face the square window hole towards the white light "sun" and position the paper so that a square of sunlight falls on the gridlines on the worksheet with the grid at 90° to the light rays. This is like the way the sun hits the ground in the summer around noon (students recorded the real angle on the Reasons for Seasons worksheet). Count how many squares the sunlight covers. Now change the angle between the grid and the light rays (taking care to keep the square hole facing straight towards the sun). This simulates how sunlight hits the ground in the wintertime. Again, count how many squares the sunlight covers. (More area is covered.) Explain that while there is still the same amount of sunlight coming through the square, it is spread over a larger area of "ground," so the ground receives less heat. That is another very important reason why it is colder in the winter. The sun is lower in the sky, so its light hits the ground at a lower angle than in the summer. The lower the angle of sunlight, the more the light is spread out, giving less heat for a given area of ground.


Protractor
Light Rays
Grid
Hole

Cut along dashed lines.

Fold along dotted lines.


The Reasons for the Seasons
Light Angle/Area Measuring Tool
Cut out this window
GROUND
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
developed by Alan Gould
Lawrence Hall of Science
University of California

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MAKING PICTURES OF MOTION

ACTIVITY B-6

GRADE LEVEL: 6-9

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What's This Activity About?

This is a simple experiment about shadow lengths, geometry, and motion, with applications to astronomy. It reinforces the concepts from the preceding activity about the height of the Sun, and how that height varies during the day and over the seasons.

What Will Students Do?

Students use a flashlight and toothpick to create a shadow and measure changes in its length as they change the position of the light.

Tips and Suggestions

- For later grades, have students measure and record in an experimenter's journal where the light source is (its angle and height relative to the toothpick) in addition to measuring the length of the shadow. Then graph the height of the flashlight vs. the length of the shadow.

What Will Students Learn?

Concepts

Geometry
Motion
The changing position of the Sun in the sky

Inquiry Skills

Observing Systematically
Measuring
Inferring

Big Ideas

Models and Simulations
Patterns of Change

MAKING PICTURES OF MOTION

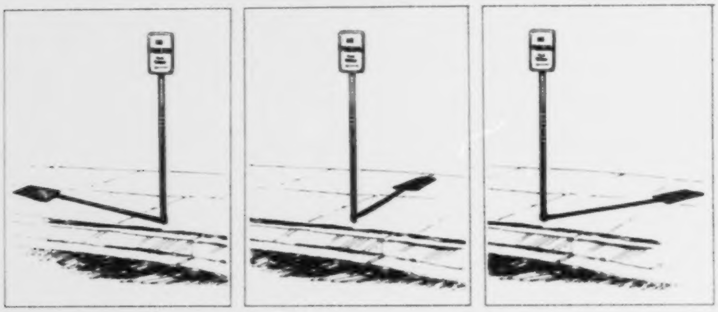
DS-4

Science Themes
geometry
motion

Science Skills
observing
inferring

Time Frame
one class period with the flashlight as a light source; additional sunny days for the sun as a light source

Materials
- ☐ *8½" x 11" paper, manila file folders, 6 x 9 file cards, or posterboard*
- ☐ *toothpicks*
- ☐ *small pieces of styrofoam (from supermarket meat trays)*
- ☐ *flashlight*



Introduction

When you step outside into the sunlight you can see many different shadows. You see shadows of people, trees, buildings, telephone poles, street signs, fence posts, and lamp posts. Have you noticed how these shadows change during the day? As the sun moves across the sky from east to west, the shadow of the flagpole in front of your school also moves. Does the shadow move from east to west or from west to east? Does its length stay the same or change? Check it out on a sunny day.

With a flashlight and a stick you can create a shadow that changes position just like the flagpole or the "no parking" sign above. And you can find more than one way to make the same changes in the shadow's length and direction.

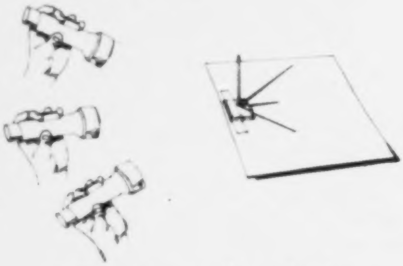
Preparation

Tape a small piece of styrofoam onto a large file card or stiff piece of cardboard. Push a toothpick into the styrofoam as shown. The piece of styrofoam should be about 2 cm square and ½ cm thick.

The Activity

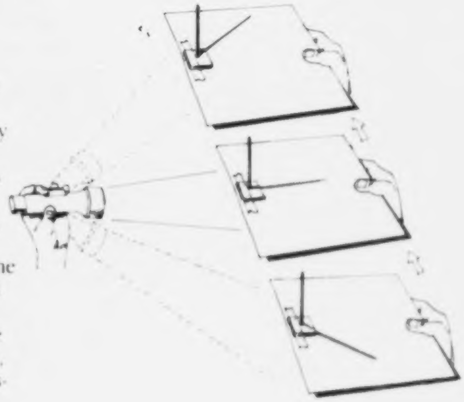
With a flashlight as your light source

Shine your flashlight on the toothpick to create a shadow line. Try different ways of making the shadow line change its direction and its length. With a flashlight as your light source you can watch the shadow line move as you make it move.



(1) *Without moving the toothpick,* can you make the direction of the shadow line change? Observe closely how a classmate makes the shadow line change direction. Notice what is moved and how it is moved.

(2) *Without moving the flashlight,* can you make the direction of the shadow line change. Do not move the flashlight, but keep the light pointed at the toothpick. Have a classmate hold the flashlight and you make the shadow line change direction. Then, exchange places and have your classmate make the shadow line change direction while you observe what is happening.



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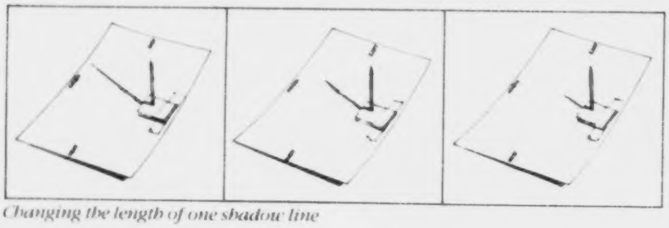
(3) Can you and a classmate find *two different ways* of making one shadow line longer and shorter in the same direction? How can you get the tip of the shadow line to move in and out *without moving the toothpick? without moving the flashlight?*

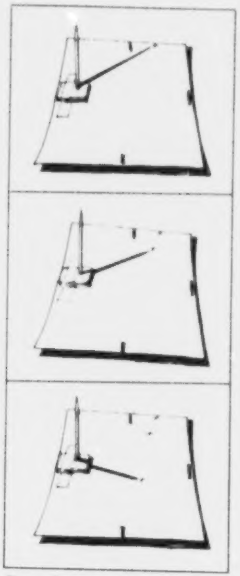


Changing the length of one shadow line

With the sun as your light source.

You can also form a shadow line by placing the toothpick in direct sunlight—either outside or in a window that faces the sun. What changes in the shadow line can you see? Will you actually see it move? How can you prove that it moves?

(1) *From hour to hour.* When you place the toothpick in the sun make sure the card it is attached to always points in the same direction. (One way is to have the north end of the card pointed north.)

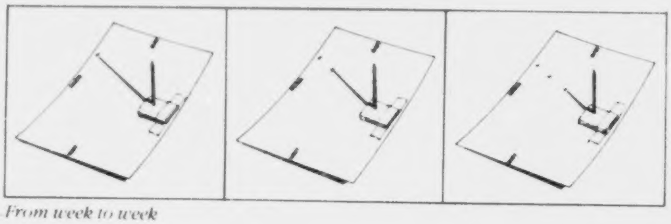


From hour to hour

Every hour mark the tip of the shadow line you observe with a small "x". Do this for several hours during the day. The series of "x's" you record will be a still picture of where the shadow line pointed during the day and how long it was. Put the date on your shadow card. If you place the card outside you must try to pick a place that is not covered by shadows of trees or buildings during the day.

(2) *From week to week.* You can also make a still picture of what happens to a shadow that points in one direction, such as northeast or north or northwest. Can you detect a change in its length from one week to the next? How long does it take before you can see a change in the length of the shadow line?

Record the length of the shadow line each week. Mark the tip of the shadow line with a small "x". Be sure that your shadow card is always facing the same way from week to week.



From week to week

Discussion and Analysis

With a flashlight as your light source

How did you and your classmates make the *direction* of the shadow line change? What moved and how did it move? What did not move?

How did you make a shadow line change only in length, while its direction stayed the same? What moved and how did it move? What did not move?

With the sun as your light source

Look at the pattern of "x's" that you made from hour to hour during the day? What moved to make the direction of the shadow line change? How did it move? What did not move? You may want to show what you mean with a flashlight.

Look at the line of "x's" that you made to mark the change in length of a shadow line from week to week. What moved to make the length of the shadow line change? How did it move? What did not move? Again, your flashlight may help you explain what you mean.

Going Further

Take the shadow pictures (the pattern of "x's") that you made in the sunlight. Use your flashlight to make a series of shadows that fit the pattern of "x's". Can you do this in two different ways? What moved and how? What did not move?

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MAKING A SUN CLOCK

ACTIVITY B-7

GRADE LEVEL: 6-8

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What's This Activity About?

Students create a small paper sundial to indicate time based on the position of the Sun in their sky. The pocket Sun Clock helps students to develop systematic observing skills, as well as a sense of "time" based on the motions of the Sun. This activity is a good one to do following "Making Pictures of Motion."

What Will Students Do?

Students will construct a small paper Sun Clock, which uses the shadow of a string to indicate the time. Students will determine their "local noon," and observe the changing shadow as the Sun moves across their sky. Students can then explain the relationship between the motion of the Sun and our concept of time.

Tips and suggestions

- Before starting the activity, borrow a compass and locate the approximate direction of (magnetic) South. Note that depending on daylight savings and your longitude, the Sun probably will not appear due South exactly at noon on a watch, according to your standard time zone. The activity corrects for daylight savings time, but does not delve into the ideas of time zones. Discussion of standard time, international time zones, and longitude can be integrated into the activity for later grades where students have a greater sense of world geography.
- This activity can be revisited during the year to investigate whether the season affects the use of the Sun Clock.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Time based on the Sun	Experimenting	Patterns of Change
Local Noon	Observing	
Cardinal Directions		

MAKING A SUN CLOCK

Our concept of time is based on the motion of the sun. In this activity students construct sun clocks. They are challenged to determine the correct orientation needed for the sun clock to function. Keeping track of the sun's shadow with the sun clock helps students visually understand the relationship between the sun's motion and our concept of time.

CONCEPT

Our concept of time is based upon the apparent motion of the sun.

OBJECTIVES

Students will:

- construct pocket sun clocks.
- determine local noon using the sun clocks.
- make observations about the passing of time using their sun clocks.
- explain the relationship between the motion of the sun and our concept of time.

MATERIALS

Pocket Sun Clock pattern (for your location)
cardboard slightly larger than the sun clock (file folders, index cards, etc.)
string, 20 centimeters (7 inches) long
glue
chalk or pencil
scissors
tape

PROCEDURE

Advanced Preparation:

Make a copy of the Pocket Sun Clock pattern for each student. (Be sure to use the pattern appropriate to your state.) If possible, copy the sun clock pattern on heavy paper, tagboard, or card stock. (If this is not available, duplicate the pattern on regular paper and have the students glue their patterns to heavier weight paper. Old file folders or large index cards are good materials.)

1. Distribute copies of the appropriate Pocket Sun Clock pattern for your location. Have students cut out the rectangular pattern.

2. Students then cut the short notches at each end, as indicated on the Pocket Sun Clock pattern. They should fold the clock along the dotted line on the pattern, making sure the hour lines are to the inside.

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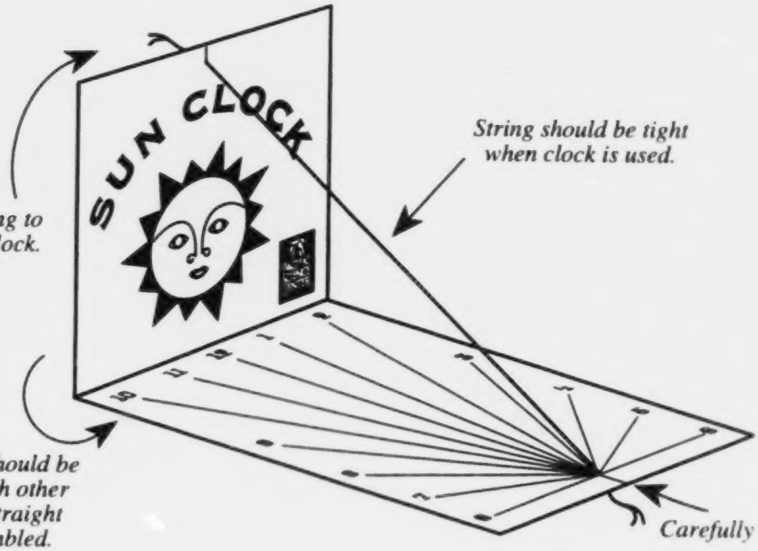
3. Have students take approximately 20 centimeters (7 inches) of string, place one end through one of the notches on the sun clock, and tape it to the back of the clock.

4. Have them stretch the other end of the string through the notch at the other end of the sun clock. The string should be adjusted so it is tight when the two panels of the clock are at a 90-degree angle. Have students tape the string's end to the back of the sun clock.

5. Ask the students to decide what they would need to make their clocks work. Have them predict if the sun clocks must be in any special position to register the correct time.

   Teacher's Note: The students should discover that the clocks must always face the same way—south. This is a good problem solving activity, so give them plenty of time to discover the required positioning of the clocks.

PROPERLY ASSEMBLED SUN CLOCK



Tape string to back of clock.

String should be tight when clock is used.

Clock faces should be at 90° to each other and string straight when assembled.

Carefully cut notches.

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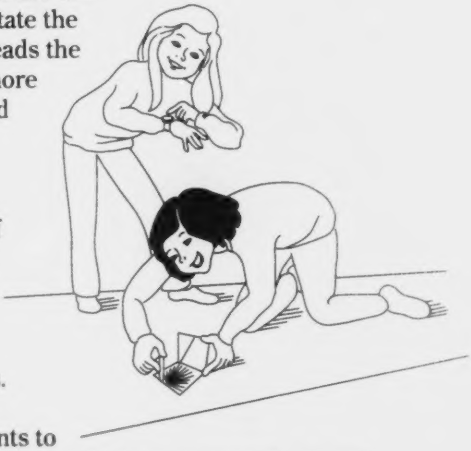
a. Before going outside to use the sun clocks, check the time on a clock or watch. If it is daylight saving time, subtract one hour to give standard time.

b. Once students have the correct standard time, take them outside to a sunny location where there is a flat surface. Be sure the location will be in the sun for at least the next half hour. The string of the sun clock must be taut. Students should rotate the clocks until the shadow of the string reads the correct time. Ask students if there is more than one way to orient the clock to read the correct time.

c. Have students use a pencil or piece of chalk to draw a box around the base of the clocks so they can remember the sun clock's orientation. They should put their initials inside the boxes so they can find their clock's location when they make the next observations.



d. Return to the classroom and ask students to predict what they will need to do to their sun clocks so they read correctly when they check the time in 15 to 45 minutes. Will they need to change the clocks' orientation? How much, if any, will they need to move them? Will more than one orientation work?

e. After 15 to 45 minutes, the students place their sun clocks back in the spots marked earlier and determine what must be done to read the correct time.

6. Discuss how to correctly orient the clocks. Did all orientations work? Is there anything special about the direction the string faces on the sun clocks?

7. After students have developed a set of instructions for correctly positioning the sun clocks, they need to remember some other details that help in their operation:
   a. Use the clock on a level spot, away from buildings and trees which create shadows.
   b. Choose an accessible location.
   c. The first time the sun clock is used, line up the string's shadow to give the same time as a clock or watch. (Don't forget to adjust for daylight saving time, if it is in effect, by subtracting one hour from the time on the clock or watch.)
   d. Draw an outline of the sun clock on the surface to get an accurate future readings.

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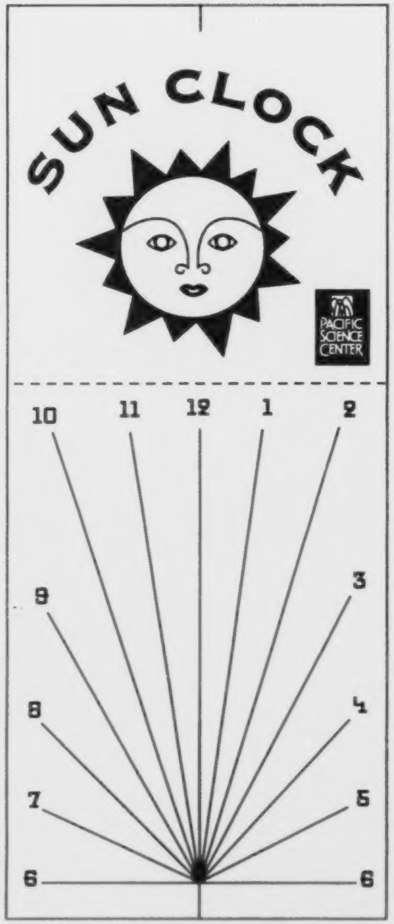
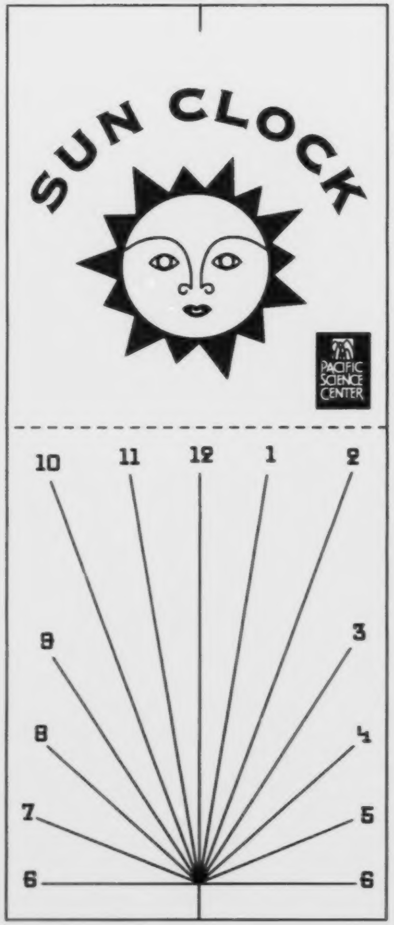
POCKET SUN CLOCK

CLOCK 1


SUN CLOCK
PACIFIC SCIENCE CENTER
10
11
12
1
2
9
3
8
4
7
5
6
6

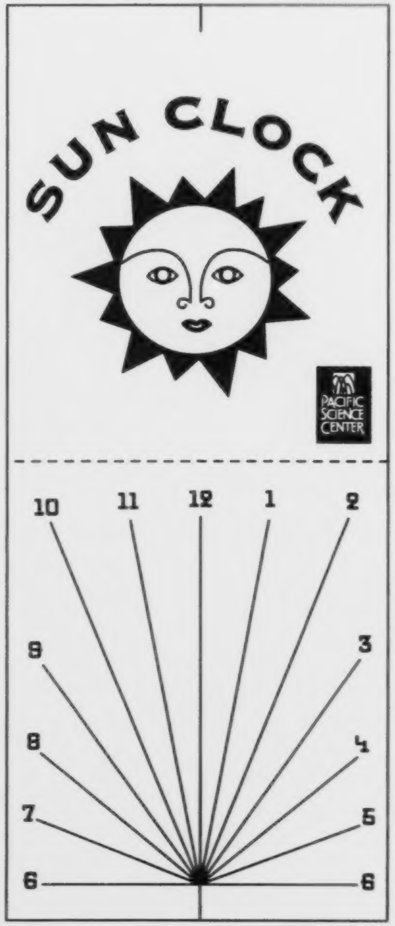
Use this Sun Clock if you live in: Southern California, Southern Nevada, Arizona, New Mexico, Oklahoma, Texas, Arkansas, Louisiana, Tennessee, Mississippi, Alabama, Georgia, Florida, North Carolina, South Carolina

CLOCK 2


SUN CLOCK
PACIFIC SCIENCE CENTER
10
11
12
1
2
9
3
8
4
7
5
6
6

Use this Sun Clock if you live in: Northern California, Northern Nevada, Utah, Colorado, Southern Wyoming, Nebraska, Kansas, Iowa, Missouri, Illinois, Indiana, Ohio, Kentucky, Virginia, West Virginia, Maryland, Delaware, New Jersey, Pennsylvania, Lower New York, Massachusetts, Connecticut, Rhode Island

CLOCK 3


SUN CLOCK
PACIFIC SCIENCE CENTER
10
11
12
1
2
9
3
8
4
7
5
6
6

Use this Sun Clock if you live in: Washington, Oregon, Idaho, Montana, North Dakota, South Dakota, Northern Wyoming, Minnesota, Wisconsin, Michigan, Upper New York, Vermont, New Hampshire, Maine, Southern Canada

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PLOTTING THE APPARENT DAILY MOTION OF THE SUN

ACTIVITY B-8

GRADE LEVEL: 9+

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What's This Activity About?

This activity is excellent for later grades, incorporating experimentation about the location and height of the Sun and their relation to the seasons. Like other Project STAR activities, this includes some challenging questions for students, along with thorough answers and guidelines for the teacher. The activity complements "The Reasons for the Seasons" from the Lawrence Hall of Science.

What Will Students Do?

Students start by investigating their preconceptions about the position of the Sun in the sky over the day and year. They use a transparent plastic hemisphere to create a model of the sky, and mark the position of the Sun in the sky on the hemisphere. The Sun's position is recorded many times in one day, creating a visible path across the hemisphere that can be studied later. From the path, students can determine the location of sunrise, sunset, and the Sun's height at noon. Alternatively, students record the position of the Sun at the same time over many days.

Tips and Suggestions

- "Plotting the Apparent Daily Motion of the Sun" builds on the concepts of horizon astronomy developed in previous activities. It does not discuss the amount of sunlight received on Earth as the Sun's position changes, nor does it describe how the Sun's position will change with the observer's latitude. These concepts are developed in the two activities that follow.
- This activity includes four extensions, enabling students to explore sunrise and sunset positions, solar motions over an entire day, and different solar paths over the year.
- As an alternative to the clear plastic hemisphere, you can use a celestial globe, such as the "Starship Earth" globe from Spherical Concepts (available through the ASP catalog).
- The plastic hemisphere may be obtained from Project STAR, Hands-On Science Materials (800) 537-8703. Order the PS-03, Sun Tracking Plastic Hemisphere, $6.00.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
The Sun's motion during one day	Observing	Patterns of Change
The Sun's height in the sky	Recording	Models
	Predicting	

PLOTTING THE APPARENT DAILY MOTION OF THE SUN

PURPOSE

To plot and discuss the Sun's apparent daily movement across the sky.

WHAT DO YOU THINK?

Your teacher will give you a plastic hemisphere. Place the square rim of the hemisphere flat on your desk.

Imagine that the sky is the inside surface of the hemisphere. As an observer, you would be standing at the center of the circle at the base of the hemisphere. This is the spot marked X in Figure 1.4. You will draw the path of the Sun as it would appear from inside the hemisphere.

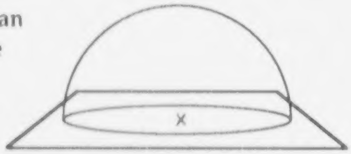

Figure 1.4

With the plastic hemisphere in front of you, choose a point on the base at one of the ridges and use a transparency pen to tag it as North and label it "N." Looking down on the dome and going clockwise from north, mark the other three ridges as East (E), South (S), and West (W).

P1. *a) Predict the following positions for the Sun for today by writing a letter on the dome. Use the letter **r** to show the position of the Sun at sunrise; the letter **n** to indicate its position at noon; and the letter **s** to indicate its position at sunset.*

b) Connect these points on the hemisphere with a curved line that represents how you think the Sun will move across the sky on this day.

P2. *From what direction did the Sun rise this morning?*

P3. *In what direction will the Sun set this evening?*

P4. *Where in the sky is the Sun at noon?*

P5. *How many hours of daylight will there be today?*

You will repeat this activity another day. Meanwhile, store your hemisphere in a safe place to prevent loss, damage, or smudging.

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MATERIALS

Figure 1.5: Hemisphere Base Diagram

cardboard sheet, 20 cm x 20 cm (8 in x 8 in)

magnetic compass

transparent tape or stapler

plastic hemisphere from the **WHAT DO YOU THINK?** section of this activity

marking pencil (Use a grease pencil if possible; sunlight may fade felt-tip inks.)

PROCEDURE

A. Tape or staple Figure 1.5 (the "base sheet") to the cardboard sheet. Then tape or staple the base of the hemisphere to the base sheet-cardboard combination so that the ridge marked "N" lines up with North on the base sheet and so that the + mark is directly under the center of the hemisphere. See Figure 1.6.

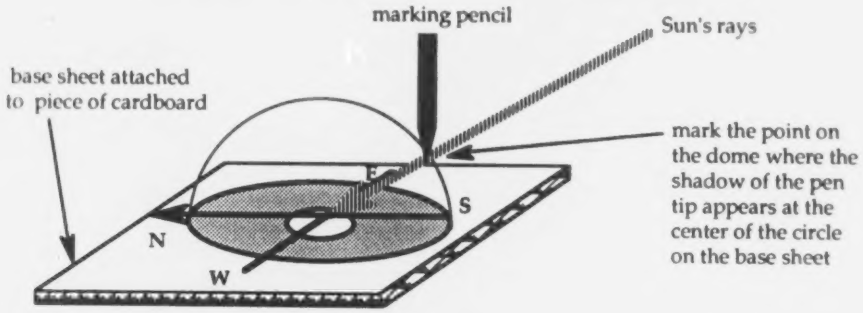
marking pencil
Sun's rays
base sheet attached to piece of cardboard
mark the point on the dome where the shadow of the pen tip appears at the center of the circle on the base sheet
E
S
N
W

Figure 1.6

B. Place the hemisphere on a flat, horizontal surface in direct sunlight. With the aid of a magnetic compass, turn the hemisphere so the ridge marked "N" points north. NOTE: Be careful not to place your hemisphere near iron or steel objects since these metals will attract your compass needle and produce an inaccurate reading. Once the dome is set in place, DO NOT MOVE IT! (Draw an outline around the cardboard with a piece of chalk just in case the hemisphere is accidentally moved.)

DO NOT STARE AT THE SUN. IT CAN DAMAGE YOUR EYES.

C. Plot the Sun's position in the following way (see Figure 1.6):

1) Carefully move the tip of the grease pencil close to the plastic hemisphere, but do not let the pencil touch the sphere.

2) Move the pencil around until the shadow cast by its tip falls directly on the + mark that is at the center of the base sheet.

3) Touch the pencil tip to the dome and at that point make a dot. The dot's shadow should fall directly on the + mark on the base sheet.

4) Repeat steps C1–C3 every 10 minutes for at least 30 minutes and longer if possible.

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5) Connect the plotted points with a line. Draw this line on the *inside* of the hemisphere. Label the line with the date and time range of C4. DO NOT ERASE THIS LINE.

DISCUSSION QUESTIONS

1. Discuss how the points and line you drew for question P1 compare with the points and line plotted in this activity.

2. From what direction did the Sun rise?

3. Where was the Sun at noon? What was the approximate angular height of the Sun at noon?

4. In what direction did the Sun set?

When you have answered these questions, erase the line you drew for question P1. Keep the line you plotted in step C.

EXTENSION

1. Bring the hemisphere and a magnetic compass home on the same day you did this activity. Follow the set-up and plotting procedures described in steps B and C. Plot the Sun's apparent motion across the sky for half an hour before sunset and for half an hour after sunrise the next morning. (You may have to wait a day or more if the sky is overcast at sunset or sunrise.) Label the lines with the dates and time ranges.

2. On a clear weekend day follow steps B and C for the entire day. Plot the points at ONE HOUR intervals only.

3. Repeat this plotting of the Sun's apparent daily motion on a clear day one month after the date of your original plot. Repeat this plotting for as many months as possible. Use a different color pen for each month.

4. Refer to an almanac or a calendar to determine the first day of each season. Plot the apparent daily motion of the Sun on the hemisphere for these days. Use a different color pen for each day.

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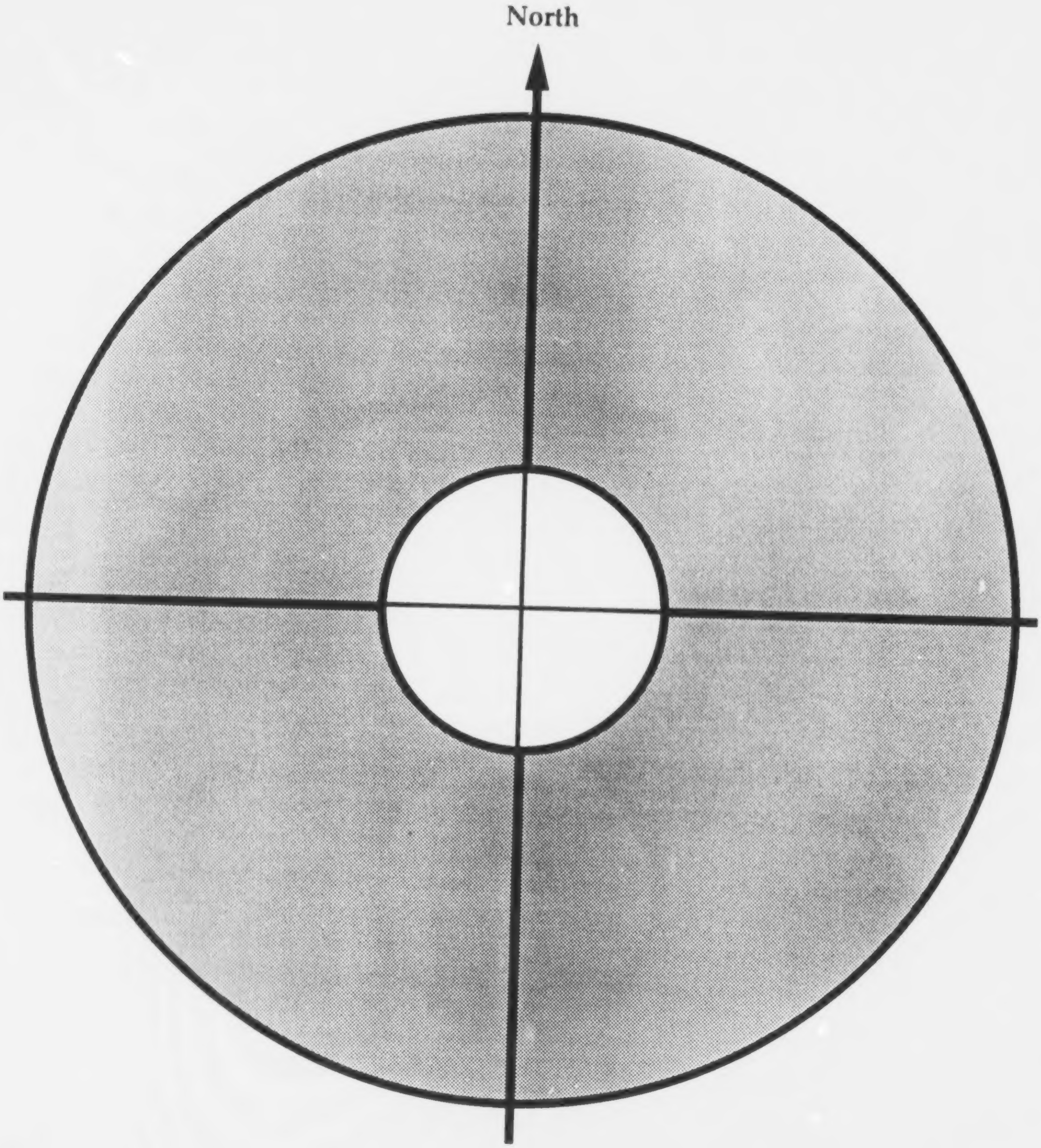

Figure 1.5 Hemisphere Base Diagram

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Teaching Notes

Class time: 45-55 minutes

1. Preconceptions

Questions P1-P5 constitute the "What Do You Think?" section for Activity 1.2. These questions ask what the student believes about the path of the Sun across the sky on a given day, including directions of sunrise and sunset and the number of hours of daylight. Many students think that the Sun rises due east, passes directly overhead at noon, and sets due west. The path plotted by the student in answer to P1 is therefore often a simple arc starting from east, passing over the top of the hemisphere, and down to the west. The idea that the Sun is overhead at noon, regardless of the time of year, is strongly held by many people of all ages and backgrounds. Expect a number of students to state 12 hours for P5; others may be more aware that the days have been getting longer or shorter and respond with values more or less than 12 hours. This activity will directly test these ideas for the date the activity is done. In combination with Activities 1.3 and 3.2, additional insight into the patterns of the Sun's apparent motions (daily and seasonal) and their causes will be gained.

2. Activity Tips

Although the plastic hemisphere is quite durable, it will dimple if too much pressure is applied with the marking pen. However, the dome can usually be popped back into shape, even if someone accidentally steps on it.

Depending on the size of your class, your schedule, and your access to an area where the hemispheres can be safely set out on the ground, you may wish to vary step C. As written, the plotting portion of the activity is designed to be completed in one class period. However, if you can leave the hemispheres in place for the day, you could have different classes plot positions over the day, or arrange to have students from one class come back during study periods, lunch, or after school to continue the plotting. This procedure would be similar to doing Extension 2 in school.

If you are going to plot paths for selected days over a period of time (such as in Extension 3), you may want to use a grease pencil instead of a felt-tip marker; many felt-tip inks fade on the plastic over a period of days or weeks. If you have time, you should experiment with your felt-tips to see how fade-resistant they are.

In step B, the alignment of the hemispheres by magnetic compass should take into account the magnetic declination at your location. Magnetic declination is the angular difference between the direction to which the needle points, which is towards the North Magnetic Pole, and the North Pole ("true north"). In the eastern United States, a compass needle points west of true north. Thus, if the declination for your region is 10° west, true north is 10° to the east (or to the right if you are facing north) of the direction the needle points. In the western U.S., a compass needle points east of true north, so true north lies to the west (or left) of the indicated direction.

3. Answers to Discussion Questions.

The answers will vary with the time of year and your location.

1. The answer will vary among your students. See the Preconceptions section for the sources of possible discrepancies between student predictions and results.

2. The answer depends upon your latitude and the time of year. During fall and winter in the continental U.S., the Sun rises somewhere to the south of due east (on the first day of fall, the

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Sun rises due east as seen from any location). For spring and summer in the U.S., the Sun rises somewhere north of east (on the first day of spring, the Sun rises due east for all locations).

3. The answer should be approximately south, and not directly overhead. By definition, the Sun is due south at local solar noon (noontime). However, for most locations local solar noon does not occur at 12:00 noon by the clock due to factors such as Daylight Savings Time and your position east or west of the central meridian of your time zone. (The time zone central meridians, or longitudes, for the continental U.S. are: Eastern = 75° West, Central = 90° West, Mountain = 105° West, and Pacific = 120° West. Find your longitude on a map or in an atlas. If you are east of your time zone's central meridian, the Sun will be at its noon position before 12:00 Standard Time; if you are west of that meridian, local solar noon will occur after 12:00 Standard Time.) At local solar noon the Sun is at its highest point in the sky for the day, but it is never directly overhead for any location in the continental U.S. Only observers at locations on or between the Tropics of Cancer and Capricorn, 23.5° North and South latitude respectively, ever see the Sun exactly overhead, and then only on two days out of the entire year (one day per year on the Tropic lines themselves).

4. The answer depends upon your latitude and the time of year. During fall and winter in the continental U.S., the Sun sets somewhere south of due west (on the first day of fall, the Sun sets due west as seen from any location). For spring and summer in the continental U.S., the Sun sets somewhere to the north of west (the Sun sets due west on the first day of spring for all locations).

4. Extensions 1-4

Because the Sun's apparent path depends upon your location and the date, you should plot the Sun's position on your own hemisphere for use as a reference for checking student plots for these extensions.

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SOLAR MOTION DEMONSTRATOR

ACTIVITY B-9

GRADE LEVEL: 7-9+

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What's This Activity About?

Truly understanding seasons requires students to appreciate the differences in the Sun's rising and setting positions, and height in the sky, for different positions around the Earth. This activity will help students investigate how the Sun's position changes during the year *for any place in the northern hemisphere*. With the Demonstrator, students can model the path of the Sun at the equator, the Arctic circle, or even the North Pole. This is another activity that helps to develop our students' three-dimensional perspective, especially of the spherical shape of the Earth.

What Will Students Do?

Students will create a small, hand-held device that accurately models the changing position of the Sun for any observer in the northern hemisphere. With the instrument, students can research questions including:

- Where will the Sun set? Where will it rise?
- How high is the Sun at noon?
- Where is the noon Sun highest or lowest?
- When during the year are day and night equally long?
- What is the motion of the Sun at the equator? At the North Pole?
- What happens on a solstice? On an equinox?

Tips and Suggestions

- Be sure to assemble the demonstrator yourself first to explore the questions to gain confidence. Making the demonstrator will take less time than the instructions might suggest at first glance.
- Consider creating one large demonstration model to help students with the instrument's use, as suggested in the activity's final page.
- Students can be directed to investigate only selected questions from the list included. The demonstrator is an excellent preparation tool if students have an opportunity to visit a planetarium, but it works equally well in a classroom with just a globe of the Earth or celestial sphere model.
- The demonstrator can be used throughout the year. Have students use it when studying world geography to recall how the Sun, hours of daylight, and seasons vary for different locations.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Latitude and its effect on the Sun's path	Experimenting	Models
Solstices	Visualizing	Patterns of Change
Equinoxes	Observing	
	Predicting	
	Inferring	
	Imagining	

Solar Motion Demonstrator

> *From paper, glue, and a brass fastener you can build a remarkably powerful device which accurately models the apparent motion of the Sun, any time of year, from any place in the northern hemisphere of Earth. It's a simple, direct way to learn the pattern of the changing solar rising and setting points—just what the builders of Stonehenge, according to Gerald Hawkins, wanted to mark. You can go far beyond Stonehenge, however, and see how the Sun moves as seen from the Equator, the North Pole, or your own hometown.*

The Solar Motion Demonstrator was designed by Professor Joseph L. Snider of Oberlin College. The design and directions for use are copyrighted by Professor Snider. You may reproduce them as needed for your own classroom or planetarium (but not for commercial purposes).

Materials

☐ Solar Motion Frame and Horizon Disk cutout sheets (photocopy masters on page 34 and 35)

☐ Photocopy paper or heavy card stock sufficient for providing each student with one Solar Motion Frame and one Horizon Disk (using blue paper for the frame and green for the disk makes an attractive product)

☐ One long (1 inch) brass paper fastener (the type with spreadable flat prongs) for each student

☐ Manila file folders (one for every student)

☐ Rubber cement or glue stick (can be shared by 2 or more students)

☐ Scissors for every student (If you will be cutting these out for the students, you may want to use a hobby knife or retractable-blade paper cutter which can cut more accurately.)

LATITUDE
MONTH
SOLA
MOTI

☐ Optional: spray rubber cement instead of gluestick (available from art supply stores)

☐ Optional: newspapers if you are using spray glue, or will be cutting with a hobby knife

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Before Class

It takes more time to read these instructions than to make a Solar Motion Demonstrator, so don't let the number of steps put you off.

If you want to save time and the gluing in this section, you can buy very low cost classroom kits, attractively printed on heavy color stock, with one finished device and all materials for 24 students, from:

The Science Source
P. O. Box 727
Waldoboro ME 04572
Phone (207) 832-6344

As you can see from the templates on pages 34 and 35, two pieces are needed for each device: the Solar Motion Frame and the Horizon Disk. These pieces must be mounted on a stiff backing. This can be achieved by gluing the Solar Motion Frame to a double thickness of manila file folder material, and by gluing the Horizon Disk to a single thickness of manila file folder.

As an alternative, you can copy the templates onto heavy card stock. The Solar Motion Frame then needs to be glued to only a single thickness of manila file folder, and the Horizon Disk does not need to be mounted at all.

1. Make enough copies of the Solar Motion Frame page and the Horizon Disk page so that each student will have one frame and one disk. If possible use blue paper. To make an even more attractive model, copy the frames on blue paper (to represent the sky) and the disks on green paper (to represent the Earth).

You can do the next three steps yourself to save time in class, or let your students do this themselves.

Spray-on rubber cement adhesive, available from art supply stores, is the fastest way to apply glue, but use this in a well-ventilated room, with lots of newspaper under your work to catch the excess spray. Brush-on rubber cement is cheaper but also requires a well-ventilated room. Glue sticks are an inexpensive, non-toxic, alternative.

2. Glue the Horizon Disks to a single thickness of manila file folder stock.

3. Glue the Solar Motion Frames to a stiffer backing material, made by gluing two pieces of manila file folder material together.

4. Using scissors or a paper cutter, separate the Solar Motion Frames and the Horizon Disks, so that you can pass out one of each piece to each student. The final trimming and assembly should be done by the students.

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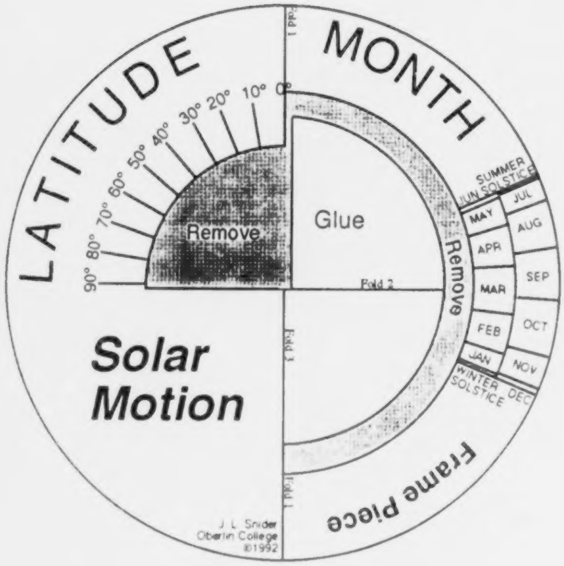
Solar Motion Demonstrator Frame Piece: Master for Duplication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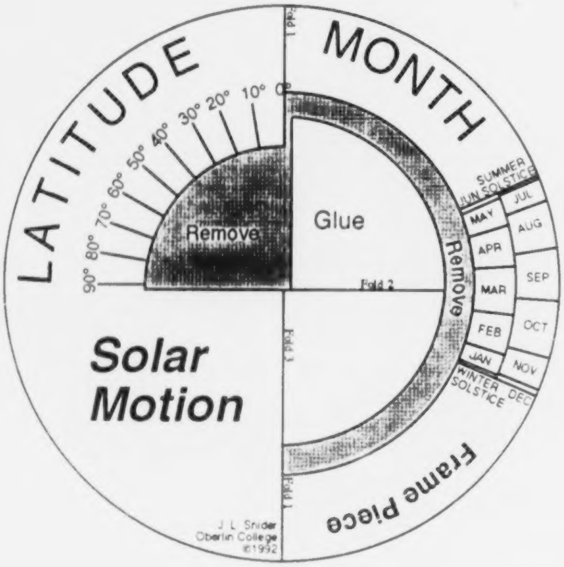
J. L. Snider
Oberlin College
©1992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Oberlin College
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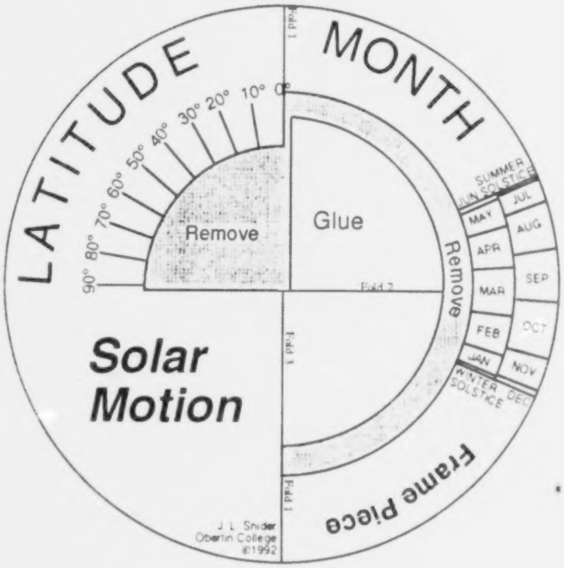
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Oberlin College
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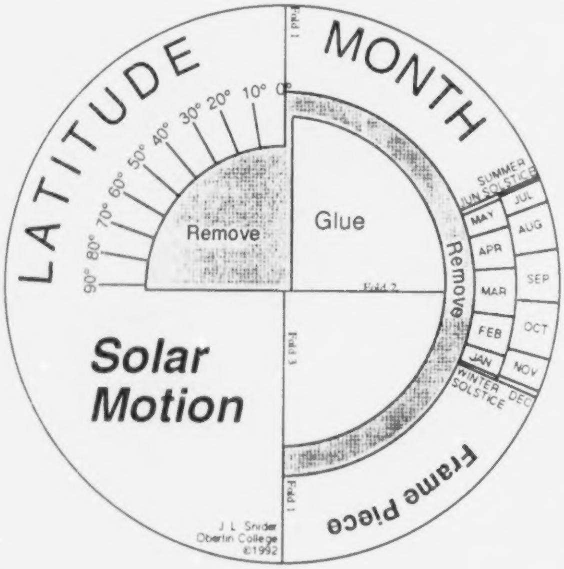
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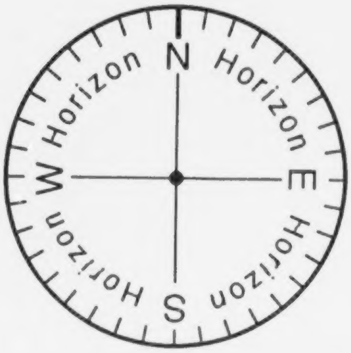
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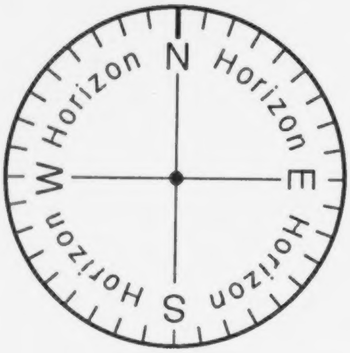
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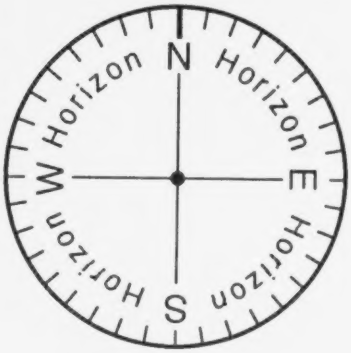
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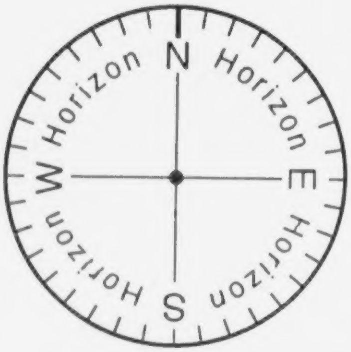
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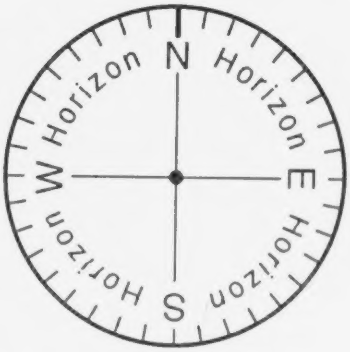
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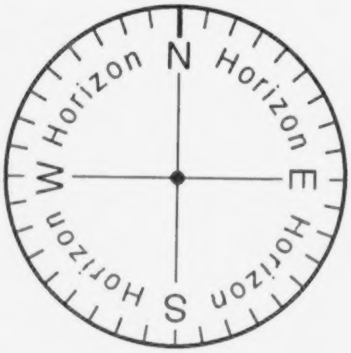
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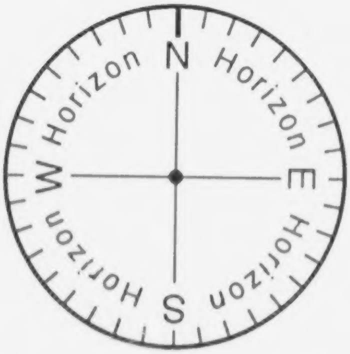
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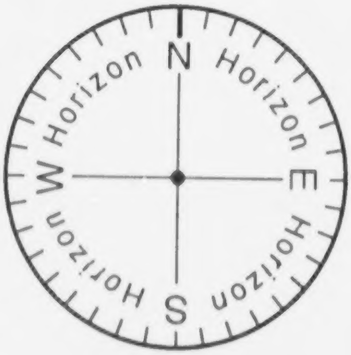
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Solar Motion Demonstrator: In Class

Part 1: Making the Solar Motion Demonstrator

1. You are going to make a remarkable device that accurately models the motion of the Sun as seen from any place in the Northern Hemisphere, at any time of the year.

Give each student a Solar Motion Frame piece and a Horizon Disk piece. Hand out scissors and glue.

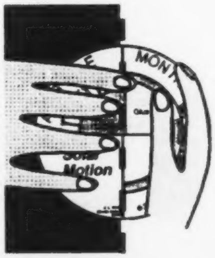
Go through each of the steps below, allowing time for each student to finish before moving to the next step.

2. With scissors cut out the Solar Motion Frame along its circular outline.

3. Carefully cut out the portions of the Frame marked "Remove" using scissors, a hobby knife, or paper cutter blade.

4. Crease the frame along a straight line passing through the hinge fold line (Folds 1 & 3: dividing the Frame vertically), by resting it against the sharp edge of a table or counter top. Line the Frame up with the edge of the counter top and rub it with the back of your scissors or other hard object until an indented groove is visible. Turn the Frame over and make an indented groove on the other side as well.

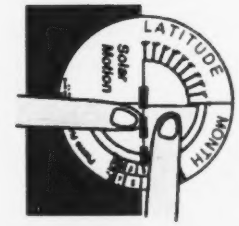
Steps
4 & 6



5. Repeat this creasing process for the short fold line (Fold 2) below the "Glue" section of the Frame.

6. Fold the Frame along the creased lines (Fold 1) so that the month half of the Frame swings all the way around to touch the latitude half of it. Repeat, pivoting the month piece in the opposite direction.

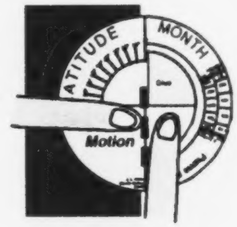
Steps
5 & 7



7. Fold the flap marked "Glue" (Fold 2) away from you and down as far as it will go, as seen from the printed side of the Frame. Bring it back to its original, flat, position.

8. Fold both the flap marked "Glue" and the quarter-circle below it with no printing on it (Fold 3) away from you as far as they will go, until the backside of the blank quarter-circle hits the backside of the Frame. Bring them back to their original, flat, position.

Step
8

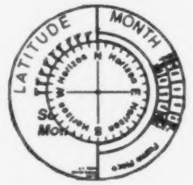


9. Use scissors to cut out the Horizon Disk along its circular outline.

10. Cut a small slot in the side of the Horizon Disk at the position of North. This slot should not be any wider than the cardboard is thick, and should be approximately 3 mm (1/8 inch) long.

11. Apply rubber cement or glue to the portion of the Frame labelled "Glue." Press the northeast quadrant of the disk against the glued portion of the Frame. Position the disk so that its north-south line lines up with the frame's hinges, and the mark for West is positioned over the 90-degree mark on the Frame. Make sure that the outer edges of the disk and Frame are accurately aligned. The correct alignment of Frame and disk is essential to the working of the device.

Step
11



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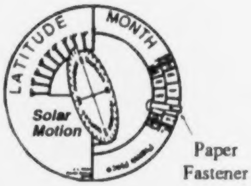
12. When the glue is dry pivot the disk on its hinge away from you through 90 degrees, and then slip the slot over the latitude scale. Make sure that the plane of the disk is perpendicular to the plane of the Frame.

13. Slip a paper fastener over the piece marked "MONTH," so that the head of the fastener is on the inner edge of the piece. Bend the head so that its plane is perpendicular to the plane of the piece. Bend one of the paper fastener's prongs around the edge of the piece so that its end lies flat against the front of the piece. Bend the other prong around and over the first one, so that its end lies flat on top of the first prong, behind the piece. The paper fastener should fit snugly around the piece, and also be easily moved to cover the appropriate date on the "MONTH" piece.



Your "Solar Motion Demonstrator" is finished!

Part 2: Using Your Solar Motion Demonstrator

How the Solar Motion Demonstrator models the Sun and the Earth:

- The "Horizon Disk" represents a piece of the surface of the Earth. You can imagine a tiny observer (represented by the black dot in the center), able to look out at the horizon in any direction, including North, East, South, and West.
- The round head of the brass paper fastener represents the Sun.
- The swinging "Month" arm of the Frame has two functions. Setting the Sun marker at the desired month adjusts for the time of the year. Swinging it from one side to the other (preferably East to West) moves the Sun in its apparent daily path over the Earth.
- The "Latitude" part of the Frame is used to adjust the Horizon Disk to set the imaginary observer at any latitude from the Equator (0°) to the North Pole (90°).

To use the Solar Motion Demonstrator, pivot the Horizon Disk along the North-South axis so that the right hand side of the disk moves away from you through 90 degrees. Line up the slot in the Horizon Disk with the edge of the Frame where it is labeled "Latitude." Slip the slot in the Horizon Disk over the Frame and align it with the latitude of your location (or one you may be interested in). The Horizon Disk must be perpendicular to the latitude part of the Frame. Next, slide the "Sun" along the outer rim of the Frame to the appropriate month.

The edge of the Horizon Disk represents the visible horizon for some imaginary person standing at the black dot in the center of the disk. To see the path the Sun makes across the sky for that particular latitude and time of year, swing the month portion of the Frame completely from the "East" to the "West" as marked on the Horizon Disk.

Compare the location of the sunrise and sunset at different times of the year. How does the length of day change with the seasons? At what latitude must you be so the Sun does not set on the longest day of the year (the summer solstice)? What would the Sun's motion look like if you lived at the North Pole?

You can answer these and many other questions with your Solar Motion Demonstrator.

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Part 3: Activities

1. Where Will the Sun Set?

Hold the device in one hand so that the Horizon Disk is horizontal. Imagine that you are very small and standing at the black dot at the center of the Horizon Disk. It would look like a large open field with a clear horizon all around you. The geographical directions of North, East, South, and West are marked around the horizon. With your other hand, smoothly pivot the piece which carries the paper fastener "Sun." As the head of the paper fastener rises above the plane of the Horizon Disk, it represents sunrise and the beginning of daytime in the imaginary world of the Horizon Disk.

When the head of the paper fastener dips below the plane of the Horizon Disk, it represents sunset and the beginning of nighttime. The perimeter of the Horizon Disk is marked in 10-degree increments. You can read the direction to the point on the horizon where the Sun sets directly from the Horizon Disk.

For example, if you are at 40 degrees north latitude, and it is late June, the Sun will set about 30 degrees to the north of west. Use your device to check this example. If you can, take the device outdoors at sunset. Align the Horizon Disk so that "N" on the disk points toward true North. Keep the Horizon Disk horizontal and raise it to eye level. Sight along the line joining the central black dot and the paper fastener head when it is located at the sunset position. This line should point to the place on the horizon where the Sun will set.

Compare the position of sunset where you live with sunset at Stonehenge (51 degrees north latitude). On a given day, does the Sun set further to the North? South? Is there any day at which the Sun sets at the same place for Stonehenge and for you? (Hint: there are two days of the year when the answer is yes.)

2. How High is High Noon?

As you swing the "Sun" around, it gets higher in the sky above the horizon. This is its "angular height" above the horizon. If you imagine yourself to be at the location of the black dot, facing the Sun, the angular height of the Sun is the angle between your line of sight to a point on the horizon directly beneath the Sun and your line of sight to the Sun. The Sun reaches its greatest angular height at a time halfway between the times of sunrise and sunset; this time is not noon on your clock—it depends on where you are located in your time zone, whether or not you are on daylight savings time, and on details of the Earth's motion around the Sun.

By using your Solar Motion model, you can get a sense of how large this maximum angular height is for various times of the year.

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3. Where will the Sun Rise?

Answer this question in the same way that you found where the Sun sets. Try using the device some day at sunrise, sighting across it to check that the Sun actually rises where the device predicts that it will. On any particular day, the Sun will rise just as many degrees north or south of East as it sets north or south of West.

4. Is Daytime as Long as Nighttime?

Pivot the piece carrying the "Sun" at a constant rate over its entire range. This corresponds to one rotation of the Earth, which takes 24 hours. Notice that the Sun lies above the horizon for part of this motion (daytime) and below it for the remainder (nighttime). You can determine the relative lengths of day and night in this way.

5. When are Day and Night Equally Long?

Use the device to show that on two particular days of the year, the Sun rises due East and sets due West for any latitude. Find the two months in which these days occur. These days are called the "spring equinox" and the "fall equinox" and are the only two days of the year when days and nights are of equal duration. The word "equinox" comes from the words meaning "equal night."
Answer: the two equinox days occur in March and September.

6. When Will the Noon Sun be the Highest or Lowest in the Sky?

Use the Solar Motion device to find the month in which the largest angular height at noon occurs. In which month does the smallest angular height at noon occur? Also, in which month does the longest day of the year occur? In which month is the shortest day of the year?

Answers: Largest angular height at noon and longest day of the year is in June, at the summer solstice. Smallest angular height at noon and shortest day of the year is in December, the winter solstice.

The word "solstice" comes from the words meaning "Sun stands still." Most of the year the rising and setting positions of the Sun are changing, moving further towards the north or south depending on the seasons. On the solstices, the rising and setting positions stop their motions north and south, and then head back in the opposite direction.

7. Why Does the Earth Have Seasons?

Move the paper fastener "Sun" up to its June position. Pivot the "Sun" and observe the relative lengths of day and night and the maximum angular height of the "Sun." Do the same with the "Sun" moved down to its December position. This demonstrates the two most important factors responsible for the seasons: the period of time over which the Sun's rays strike the ground (the length of day), and the angle at which they strike the ground.

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8. Can You Always See a Sunset?

Actually, there are places on Earth where the Sun doesn't set. Explore the range of latitudes and times of year for which the paper fastener "Sun" remains above the Horizon Disk as you pivot it through an entire rotation. This corresponds to a 24-hour day, with the Sun still above the horizon at midnight. The phrase "land of the midnight Sun" is often used to describe the places where this occurs. For an observer anywhere north of the "Arctic Circle" (about 66½°latitude) the Sun will not set on at least one day of the year.

9. When and Where Will the Sun Pass Directly Overhead?

A point in the sky directly over your head is called the **zenith**. To find out when and where the Sun passes through the zenith, move the "Sun" to a position late in June and pivot it through its daily motion to see if it passes directly overhead (assuming that you are at the location of the black dot at the center of the Horizon Disk). Change the latitude setting of the Horizon Disk until you find a latitude at which the Sun passes through the zenith for an observer at that latitude. Explore the range of latitudes and times of year for which the Sun passes through the zenith.

Answer: For an observer north of the "Tropic of Cancer" (at about 23½ degrees north latitude) the Sun will never pass through the zenith. People who live along the Tropic of Cancer can see the Sun at the zenith only in June at the summer solstice. For lower latitudes than this, the Sun will pass through the zenith on only two days of the year. Can you tell approximately which days these are?

South of the equator, the behavior is similar, but the order of months on the Solar Motion Demonstrator would have to be reversed for southern latitudes. Observers along the Tropic of Capricorn (at 23½ degrees South) see the Sun at the zenith only in December on their summer solstice. People South of the Tropic of Capricorn never see the Sun at the zenith.

10. What Path Does the Sun Take at the Equator?

Set the Horizon Disk to a latitude of 0°. Imagine that you are an observer positioned at the black dot at the center of the Horizon Disk. Vary the time of year and see how the path of the Sun across the sky changes. What can you say about how the rising Sun appears to move in relation to the horizon? Notice that the setting Sun moves in the same way. At what times of year does the Sun pass through the zenith? *Answer*: March and September (the equinoxes)

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11. What is the Motion of the Sun for an Observer at the North Pole?

Set the Horizon Disk to a latitude of 90°. Again, imagine that you are positioned at the black dot at the center of the Horizon Disk. Vary the time of year and see how the path of the Sun across the sky changes. What can you say now about the motion of the Sun in relation to the horizon? Do you see that there will be six months of light and six months of darkness at the North Pole?

12. Would Stonehenge work if it were moved to your home town?

Set the Horizon Disk for the latitude of Stonehenge, 51° north latitude. Write down the rising and setting positions of the Sun for the summer and winter solstices. Now set the Horizon Disk for the latitude where you live. Again record the rising and setting positions of the Sun for the summer and winter solstices.

Unless you live close to the same latitude as Stonehenge, you will find that the rising and setting positions are different. To make a Stonehenge in your hometown, you would have to redesign Stonehenge, changing its symmetry, to make it function as a solstice marker in the way Hawkins suggests.

Ideas for Further Activities:

You will be able to think of other ways in which you can use the "Solar Motion" device to increase your understanding of how the Sun appears to move in relation to the earth. Here are three.

1. Imagine yourself standing at the black dot at the center of the Horizon Disk. Try holding the "MONTH" piece fixed in space with your right hand, as you turn the rest of the device through its complete range of motion. As you do this, think of the Sun as being fixed in space, while the Earth's rotation turns you around with respect to the Sun. This is more nearly the situation in real life.

2. Try using the device as a compass. Set the "Solar Motion" model to your latitude and the time of year. Go outside and hold the device so that the Horizon Disk is horizontal. Pivot the "MONTH" piece and at the same time turn the compass piece (keeping its plane horizontal) so that the "N-S" line points in various directions. Your objective is to make the shadow of the "MONTH" piece be as thin a line as possible, while at the same time the shadow of the paper fastener "Sun" falls on the black dot at the center of the Horizon Disk. When you have achieved this, the Horizon Disk will show you the correct geographic directions.

3. Try constructing a giant Solar Motion Model. You can use a photocopier to enlarge the Frame and the Horizon Disk. You might want to mount these on stiffer cardboard, artists' "foamcore" material, or plywood. You may need to make stronger hinges out of cloth, or use metal hinges from a hardware store.

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MODELING THE REASONS FOR THE SEASONS

ACTIVITY B-10

GRADE LEVEL: 9+

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What's This Activity About?

Most people have the misconception that seasons are caused by the varying distance between the Earth and Sun, with summer occurring when the Earth is closest and winter when the Earth is farthest from the Sun. However, just the opposite is true: our planet is closest in January, and farthest in July. Seasons are not caused by variation of the Earth-Sun distance.

This activity offers students numerical proof that the Earth-Sun distance does *not* account for seasons. The entire activity is presented as a complete scientific investigation and it models the scientific method extremely well. Students state their hypothesis, analyze actual data, make measurements, draw graphs, and develop their conclusions.

What Will Students Do?

Students examine two images of the Sun, taken six months apart. They hypothesize why the images are different, and relate that hypothesis to seasonal temperature variations. Then students measure the apparent diameter of the Sun for 12 months, and calculate the approximate Earth-Sun distance for each observation. Students graph their data, and infer that: 1) Seasons are not caused by variation of the Earth-Sun Distance 2) The Earth's orbit is not highly elliptical, but quite close to being circular.

Tips and Suggestions

- We have reduced chart 3.2, used by students to measure the Sun's apparent diameter. The reduction has changed the scale. If you use the accompanying page as a copy master, you must establish your own conversion scale: measure the 12 solar diameters, determine the average, and multiply that average by 150,000,000.

  Example

  Based on the data provided on page 33, the average solar diameter on the masters (before copying) was 11.425 cm. 11.425 X 150,000,000 = the conversion factor: 1,713,750,000. Students divide this number by their measurement of the Sun's diameter for a particular month to obtain the Sun's approximate distance.

- If in reproduction the apparent solar diameters in Chart 3.2 are smaller, the average would be smaller, and the conversion factor would also be smaller. The approximate solar distances should still be close to the distances below:

Jan. 12:	147,100,000 km	Feb. 11:	147,700,000 km
Mar 26:	149,000,000 km	April 10:	150,300,000 km
May 23:	151,700,000 km	June 15:	153,000,000 km
July 12:	153,000,000 km	Aug. 17:	152,300,000 km
Sept. 14:	150,300,000 km	Oct. 15:	150,300,000 km
Nov. 16:	147,700,000 km	Dec. 15:	147,700,000 km

(Note that the data were rounded off. Based on the approximate nature of the measurements, keeping more significant digits would not be meaningful.)

- Do this activity before or after "The Reasons for Seasons."
- The process demonstrated here can also be used for the Moon, which is also on an elliptical orbit, with the Earth-Moon distance varying by about 5.5%. Students can examine photos of the full Moon taken during different months to analyze its changing distance from Earth.

What Will Students Learn?

Concepts

Earth-Sun orbital distance and shape
Apparent size decreases with distance
Seasons

Inquiry Skills

Measuring
Calculating
Inferring
Reasoning

Big Ideas

Scale
Patterns of Change
Interactions

MODELING THE REASONS FOR THE SEASONS

PURPOSE

To plot the distance from the Earth to the Sun and examine the reasons for the seasons.

WHAT DO YOU THINK?

Figure 3.14 shows two pictures of the Sun taken six months apart with the same camera, at the same time of day, from the same location.

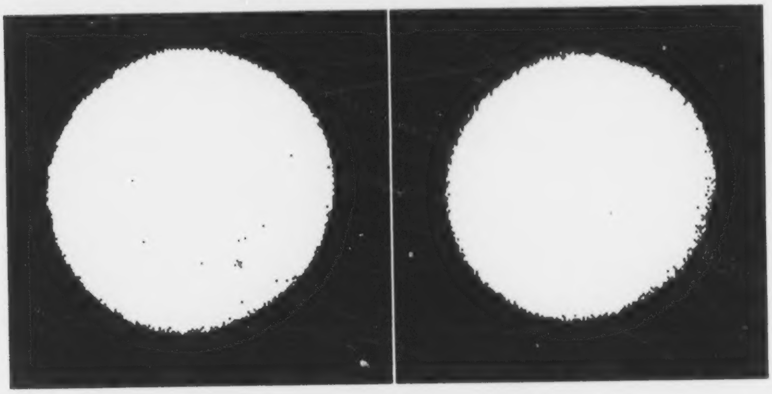

Figure 3.14

P1. *Are the images of the Sun the same size?*

P2. *If they are not the same size, how could you explain the difference?*

P3. *In which month of the year do you think each picture was taken?*

P4. *In which month or months of the year is your weather the warmest?*

MATERIALS

1 metric ruler
Chart 3.2
calculator
pencil
Graph 3.1 or 3.2 (metric or English version, depending on teacher's instructions)
felt-tip pen

PROCEDURE

A. Look at Chart 3.2 (adapted from photographs of the Sun published by R. A. R. Tricker in *Paths of the Planets*). Each rectangle is a section taken through the middle of the Sun from a larger picture. See Figure 3.15.

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B. Measure the length of each rectangle to the nearest tenth of a centimeter and record your measurements on Chart 3.2. Make sure you keep track of which length goes with which date!

C. For the specific date of each strip, calculate the distance to the Sun by dividing the conversion factor (provided by your teacher) by the length of each strip.

D. Record the distance to the Sun corresponding to each measured diameter on Chart 3.2. Again, keep track of which distance goes with which diameter.

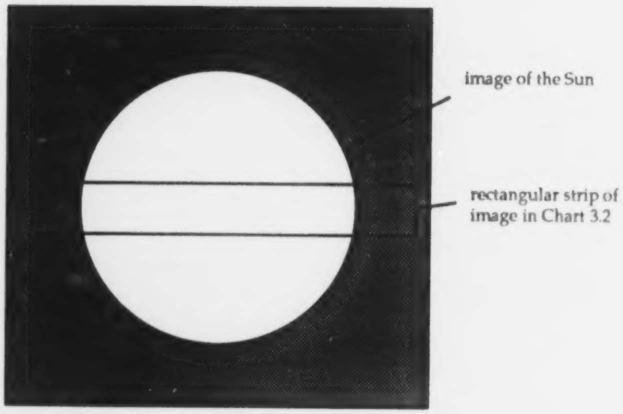

Figure 3.15

E. Plot the distance of the Earth from the Sun for each date on Graph 3.1 (or Graph 3.2 if you use miles). Because the dates of the strips are not at the beginning of each month, you will have to estimate the position of the Earth for each date on the graph.

F. Connect the points on the graph with a smooth curve. Use a pencil first, then trace over this penciled curve with a felt-tip marker.

DISCUSSION QUESTIONS

1. What does this curve tell you about the Earth's orbit?

2. In what month is the Earth farthest from the Sun?

3. In what month is the Earth closest to the Sun?

4. Compare the answers from the two previous questions to your predictions regarding Figure 3.14.

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From your measurements, calculations (step C), and Graph 3.1 or 3.2, answer the following questions:

5. Describe what your graph shows.

6. What conclusions can you draw from the observation that the Sun has a different apparent size in the summer than in the winter?

7. Do the months of your warmest weather include the month when the Earth is closest to the Sun?

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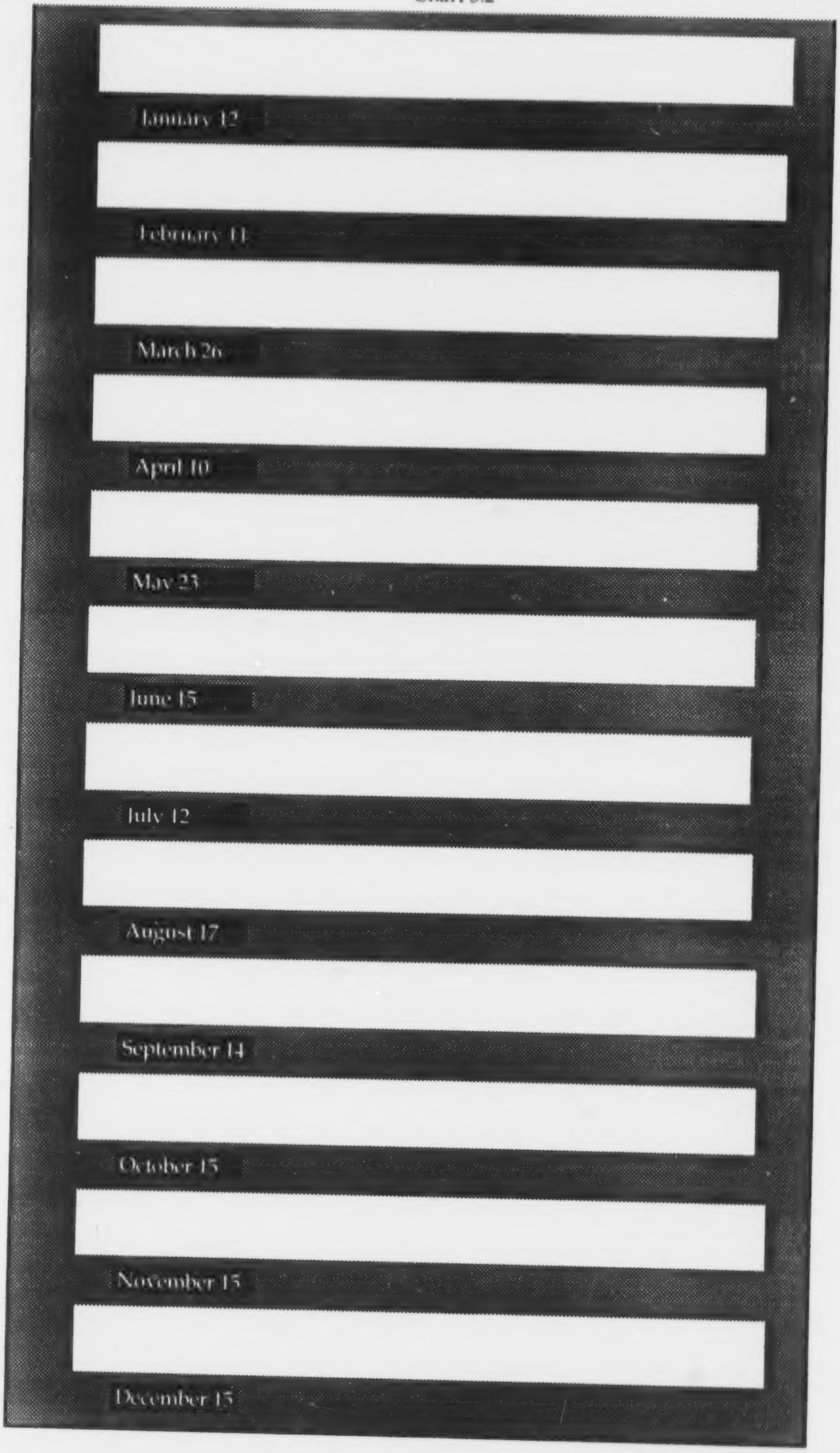
Measured Length

Chart 3.2

Calculated Distance


January 12
February 11
March 26
April 10
May 23
June 15
July 12
August 17
September 14
October 15
November 15
December 15

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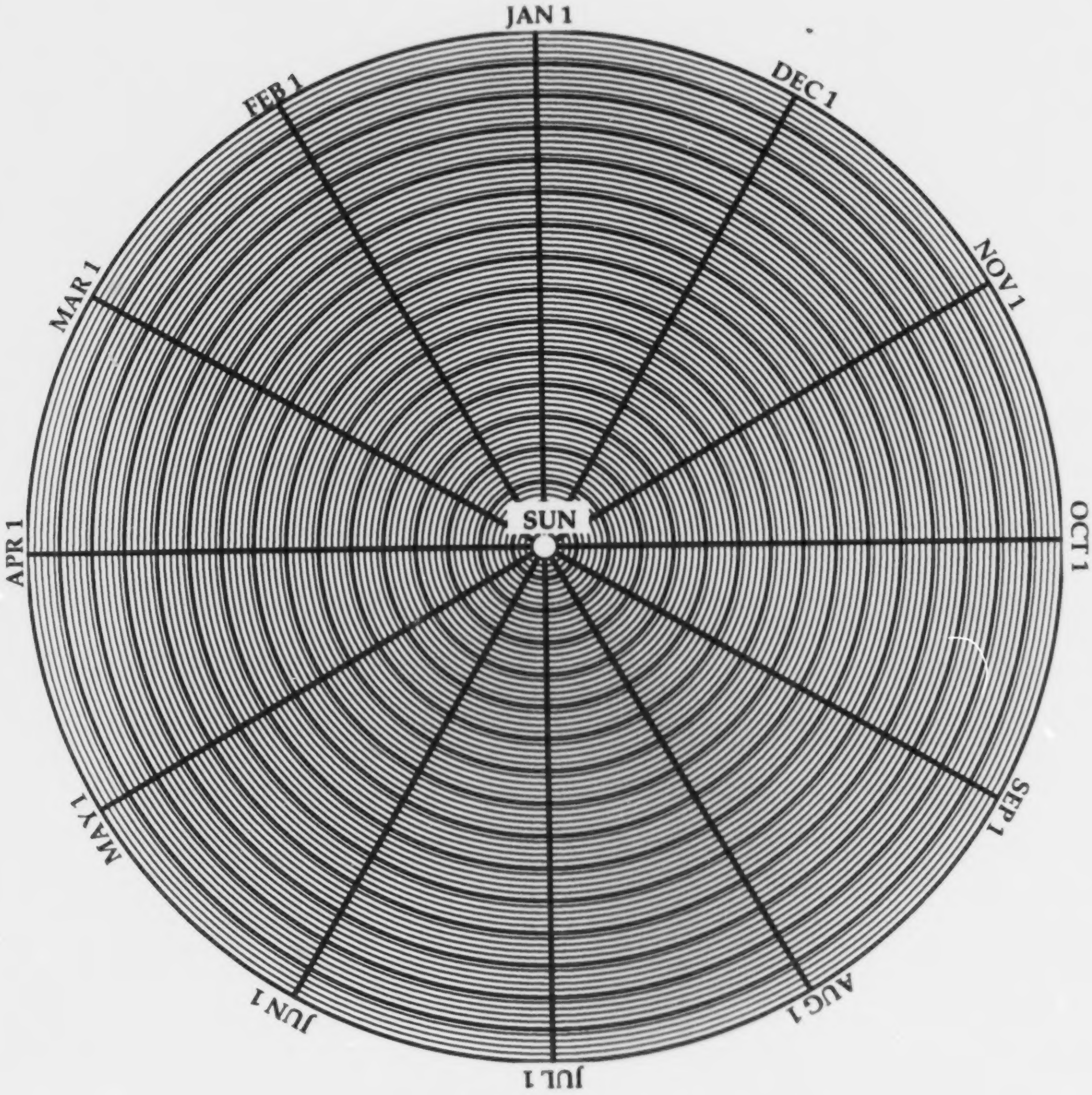
BEST COPY AVAILABLE


JAN 1
DEC 1
NOV 1
OCT 1
SEP 1
AUG 1
JUL 1
JUN 1
MAY 1
APR 1
MAR 1
FEB 1
SUN

Graph 3.1 EARTH-SUN DISTANCE FOR ONE YEAR

The heavy printed circles are separated by 10 million kilometers.
The lighter circles are spaced 2 million kilometers apart.

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Teaching Notes

Class time: 40-50 minutes

1. Preconceptions

The "What Do You Think?" section includes P1-P4. These questions probe student ideas concerning the causes of the seasons. Confronted with the two photographs of the Sun taken six months apart, most students (and adults) indicate that the larger image was taken in June (or some other summer month) and the smaller image was taken in December (or another winter month).

It is a deeply held and widespread misconception that the Earth is closer to the Sun in summer than it is in winter. It certainly seems to make sense (and it is true for locations south of the equator!). However, the Earth is actually nearest to the Sun (perihelion) around January 3 and farthest from the Sun (aphelion) on about July 5. While it is true that the Sun's heating effect increases as the distance to the Sun decreases, the change in heating due to the relatively slight difference in distance between perihelion and aphelion (about 5 million kilometers, compared to an average distance of nearly 150 million kilometers) is far overshadowed by the effect caused by the much greater change in the angular height of the Sun above the horizon at noontime and the number of hours of daylight. Thus, the most significant factor in causing the seasons is the tilt of the Earth's axis with respect to the perpendicular to the Earth's orbital plane, not the varying distance from the Earth to the Sun.

This activity demonstrates that the Earth's orbit is very nearly circular and that perihelion occurs during the northern hemisphere winter. Combined with the experiences from Activity 3.2, students should come away from Activity 3.3 with the concept that the cause of the seasons is related to the Earth's axis being tilted with respect to the perpendicular to the Earth's orbital plane, not the shape of the Earth's orbit or the EarthSun distance.

NOTE: Perihelion and aphelion are not used in the text because the words are not needed by the students to understand the reasons for the seasons, or any other concept in the text.

2. Activity Tips

The students plot the orbit of the Earth from images of the Sun taken once a month for one year. Two plotting graphs (Graph 3.1) are provided, one in metric (SI) ,units, the other in English units.

Step B:

The images in Chart 3.2 are aligned along their left-hand edges. You may want to have your students use a ruler to draw a line along the left-hand edges to facilitate measuring the image lengths. If you look at the right-hand edges of the images from a distance, or view the images at an angle by tilting the page away from you, you can see that the image lengths are not the same and do follow a pattern of decreasing-increasing lengths. Reasonable values for image lengths from Chart 3.2 as printed in the text on page 68 are listed below. Students should be able to make their measurements to within 0.1 cm of these values.

January 12: 11.65 cm
February 11: 11.6 cm
March 26: 11.5 cm
April 10: 11.4 cm
May 23: 11.3 cm
June 15: 11.2 cm

July 12: 11.2 cm
August 17: 11 Th
September 14: 11.4 cm
October 15: 11A cm
November 15: 11.6 cm
December 15: 11.6 cm

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Step C:

The conversion factors are not given in the text because photocopying may cause slight changes in image size. Thus, you should photocopy Chart 3.2 and then make your own measurements of the image lengths from the photocopied version that your students will use. The metric conversion factor is obtained by multiplying the approximate average Earth-Sun distance, 150,000,000 km, by the average length of the 12 images on Chart 3.2. The English conversion factor is derived by multiplying the approximate average Earth-Sun distance (92,500,000 miles) by the average image length. Either factor will yield approximate distance values. Even if approximations and "rounding off" are used, the resulting plot of the Earth's orbit (Graph 3.1) should be accurate at the scale that it is plotted.

3. Discussion Questions

1. The curve represents the orbit of the Earth around the Sun. The curve is very nearly a perfect circle.

2. Based on the measured image lengths, the student should conclude that the Earth is farthest from the Sun in June or July. Interpolation of the results for June 15 and July 12, suggests that the Earth is farthest from the Sun around July 1, which is true.

3. Based on the measured image lengths, the student should conclude that the Earth is closest to the Sun in January. Examination of the image measurements and Graph 3.1 indicates that the Earth is nearest to the Sun around January 12; the actual date varies from year to year, but occurs about January 3.

4. Results of this comparison vary with student predictions, but many, if not most, students will have made predictions opposite from their results.

5. Graph 3.1 shows the path of the Earth around the Sun. It shows that this path is very nearly a circle. It also shows that the Earth is closest to the Sun in January and farthest from the Sun in July.

6. The difference in the apparent size of the Sun can be explained by one of two models. Either the Sun actually expands and contracts in size during this period, or the distance between the Earth and the Sun changes, with the Sun appearing largest when the Earth is nearest to it. Data not presented in this activity confirm that it is the distance between the Sun and the Earth that changes, not the actual diameter of the Sun. If the Sun's diameter did vary over one year, images of the Sun made by interplanetary spacecraft should show such a change; however, no such annual change has been observed.

7. It is warmest in late July or early August (for locations in the continental U.S. under average weather conditions). The Earth is closest to the Sun in January, when the weather is normally the coldest of the year. Therefore, the distance between the Earth and the Sun certainly does not have a decisive effect upon the seasons.

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RESOURCES FOR EXPLORING THE SUN

by Andrew Fraknoi
Astronomical Society of the Pacific
390 Ashton Avenue
San Francisco, CA 94112

Books and articles marked with a • are especially useful for those just becoming familiar with the subject.

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

The Sun in General

- • Wentzel, D. *The Restless Sun.* 1989, Smithsonian Inst. Press. Probably the best layperson's introduction, by an astronomer.
- • Kippenhahn, R. *Discovering the Secrets of the Sun.* 1994, J. Wiley. A fine up-to-date introduction for the beginner.
- • Friedman, H. *Sun and Earth.* 1986, Scientific American Books/W. H. Freeman. An illustrated review with good material on how the Sun affects the Earth.

Frazier, K. *Our Turbulent Sun.* 1983, Prentice Hall. Nice review by a science journalist.

Goodwin, J., et al. *Fire of Life.* 1981, Smithsonian Inst. Press. A coffee-table introduction to the Sun in science, legend, and culture.

Hufbauer, K. *Exploring the Sun: Solar Science Since Galileo.* 1991, Johns Hopkins Press. A scholarly history of how we found out about the properties of the Sun.

Pasachoff, J. "The Sun: A Star Close-Up" in *Mercury*, May/June 1991, p. 66. A good introduction to how the Sun works.

Gibson, E. "The Sun As Never Seen Before" in *National Geographic*, Oct. 1974, p. 494. Observations from Skylab, a space laboratory.

- • Jaroff, L. "Fury on the Sun" in *Time*, July 3, 1989, p. 46. Nice primer on the surface and inside of the Sun.

MacRobert, A. "Close-up of a Star" in *Sky & Telescope*, May 1985, p. 397.

Golub, L. "Heating the Sun's Million Degree Corona" in *Astronomy*, May 1993, p. 27.

Nichols, R. "Solar Max: 1980-1989" in *Sky & Telescope*, Dec. 1989, p. 601. Good summary of the work of a satellite dedicated to observing the Sun.

Talcott, R. "Seeing the Unseen Sun: The Ulysses Mission" in *Astronomy*, Jan. 1990, p. 30.

Connecting the Sun and the Earth's Long-term Climate

Eddy, J. "The Case of the Missing Sunspots" in *Scientific American*, May 1977, p. 80.

Kanipe, J. "The Rise and Fall of the Sun's Activity" in *Astronomy*, Oct. 1988, p. 22.

Overbye, D. "John Eddy: The Solar Detective" in *Discover*, Aug. 1982, p. 68. On the scientist who demonstrated the connection between the Sun's activity and the Earth's climate.

Observing the Sun for Yourself

Burnham, R. "Observing the Sun" in *Astronomy*, Aug. 1984, p. 51.

Chou, R. "Safe Solar Filters" in *Sky & Telescope*, Aug. 1981, p. 119.

- • Dilsizian, R. "Photographing our Nearest Star" in *Astronomy*, May 1987, p. 38.

Hill, R. "Equipped for Safe Solar Viewing" in *Astronomy*, Feb. 1989, p. 66.

McIntosh, P. & Leinbach, H. "Watching the Premier Star" in *Sky & Telescope*, Nov. 1988, p. 486.

SELECTED READINGS FOR STUDENTS

Grades 4-6

Asimov, I. & Reddy, F. *The Sun and Its Secrets.* 1994, Gareth Stevens.

Couper, H. & Henbest, N. The Sun. 1987, Franklin Watts.

Estallela, R. *Our Star: The Sun.* 1993, Barron's Educational.

Ridpath, I. *The Sun.* 1988, Schoolhouse Press.

Walz-Chojnacki, G. "The Star Next Door" in *Odyssey*, 1991, issue 2, p. 10. Nice introduction to the Sun as a star.

Algozin, M. "Ulysses: Mission to the Nearest Star" in *Odyssey*, 1991, issue 2, p. 4.

The June 1994 issue of *Odyssey* magazine was devoted to the Sun.

Grades 7-9

Darling, D. *The Sun: Our Neighborhood Star.* 1984, Dillon Press.

Davis, D. & Levasseur-Regourd, A. *Our Sun and the Inner Planets.* 1989, Facts-on-File.

SELECTED AUDIOVISUAL MATERIALS

Secrets of the Sun (1994 slides set from the Astronomical Society of the Pacific) 32 slides showing and explaining solar activity, structure, and telescopes.

The Solar Sea (an episode of the 1986 Planet Earth television series, from the Annenberg/CPB Project or the Astronomical Society of the Pacific) Examines connections between the Earth and the Sun.

The Sun in Action (1990 slide set, Armagh Planetarium/Hansen Planetarium) A set of 20 slides showing the Sun and its activity, from Earth and from space.

The Sunspot Mystery (1977 video, Time-Life Films) An episode of the NOVA public television series on connecting the sun and Earth's climate.

A number of short films showing solar activity can be rented from the Big Bear Solar Observatory, Solar Astronomy (264-33), Calif. Institute of Technology, Pasadena, CA 91125.

C

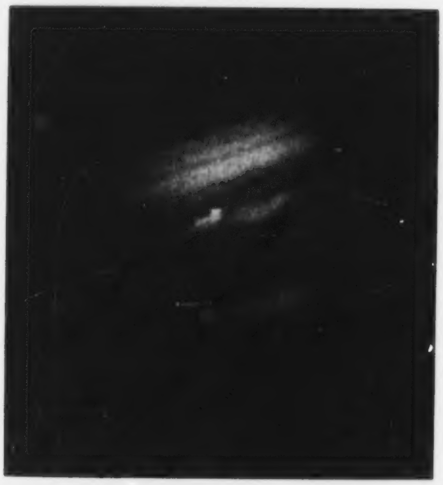
THE PLANETS

ACTIVITIES INCLUDED IN THE PLANETS

ACTIVITY Grades	1	2	3	4	5	6	7	8	9	10	11	12
						ESTIMATED GRADE LEVEL						
C-1. The Earth's Shape and Gravity Students discuss the Earth's shape and how objects fall.				▫	■	■	■	■	■	■	■	■
C-2. What Shape Is the Earth? Students compare shadows on a map and a globe to investigate the Earth's shape.						▫	■	■	■	▫	▫	▫
C-3. How Big is the Earth? Students follow the reasoning of Eratosthenes to estimate the size of the Earth.								■	■	■	■	■
C-4. Observing a Planet Students learn how to identify a "wandering star" (or planet) and join in an outdoor simulation of planetary motion.				■	■	■	■	■	■	■	■	■
C-5. Staying Up While Falling Down Using a ball, string, and weight, students simulate a body kept in an orbit by gravity.							■	■	■	■	▫	▫
C-6. Morning Star and Evening Star Using a ball and a bright light, stuents explore why Venus is visible in the sky at only particular times of day.			▫	▫	▫	■	■	■	▫	▫	▫	▫
C-7. Venus Topography Box Students create a map of a solid surface which they cannot see.				■	■	■	■	■	■	■	■	■
C-8. Martian Canals Students relate drawings of a random pattern to artificial canals on Mars.				■	■	■	■	■	■	▫	▫	▫
C-9. Planet Picking Students classify features in a series of photographs.				■	■	■	■	■	■	▫	▫	▫
C-10. Solar System Bingo A special version of Bingo helps students learn about the properties of the planets.			▫	■	■	■	■	■	■	▫	▫	▫
C-11. Can You Planet? Students use graphs and Venn diagrams to classify the characteristics of the planets.				■	■	■	▫	▫	▫			
C-12. How High Can You Jump On Another Planet? Students find their weight and how high they can jump on other planets.				▫	▫	■	■	■	■	▫	▫	▫

■ - Grade levels recommended by authors ▫ - Can be extended to these grade levels.

ABOUT THE ACTIVITIES:
THE PLANETS



KEY IDEAS IN "THE PLANETS"

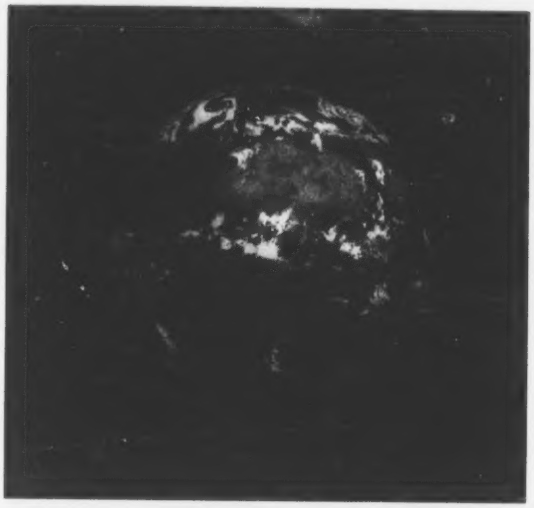
- To fully understand the Earth as a planet, students need to grasp both the Earth's shape and gravity concepts.
- Planets can be shown as different from stars in two essential ways: their appearance and their motion.
- By the end of 5th grade, students should recognize that "the Earth is one of several planets that orbit the Sun, and the Moon orbits around the Earth."
- By the end of 8th grade, students' comprehension of planets should encompass aspects such as relative sizes, composition, surface features, interior structure, orbits, moons, and rings.
- By the end of 12th grade, students should also understand the role of gravity in forming and maintaining planets, stars, and the solar system.

Which planet is closest to us? The Earth of course! If you hesitated a bit before answering the question correctly, it is probably because (if you can recall your elementary astronomy education) you probably understood quite a bit about the planets of the solar system before realizing that you lived on one of them. It is by no means intuitive that the apparently flat Earth beneath our feet is really a huge ball in space. And once students understand the spherical Earth concept, many are concerned that people who live at the "bottom" of the ball might fall off. So, to fully understand the Earth as a planet, students need to understand both the Earth's shape and gravity.

Although understanding planets as actual places is very difficult for students in the earliest grades, by grades 3-5 there are a great many things that students can learn about them. The *Benchmarks for Science Literacy* suggests that students start studying planets using both the naked eye and telescopes: "Planets can be shown as different from stars in two essential ways—their appearance and their motion. When a modest telescope or a pair of binoculars is used instead of the naked eyes, stars only look brighter—and more of them can be seen. The brighter planets, however, clearly are disks. (Not very large disks except in good-sized telescopes, but impressive enough after seeing a lot of stars.) The fixed patterns of stars should be made more explicit, although learning the constellation names is not important in itself. When students know that the star patterns stay the same as they move across the sky (and gradually shift with the seasons), they can then observe that the planets change their position against the pattern of stars." (*Benchmarks*, page 62.)

By the end of 5th grade, students are expected to bring together their understanding of the Earth's shape and gravity with what they have learned about planets, and recognize that "The Earth is one of several planets that orbit the Sun, and the Moon orbits around the Earth." (*Benchmarks*, page 63.) By eighth grade, their understanding should become more detailed: "Nine planets of very different size, composition, and surface features move around the sun in nearly circular orbits. Some planets have a great variety of moons and even flat rings of rock and ice particles orbiting around them. Some of these planets and moons show evidence of geologic activity. The Earth is orbited by one moon, many artificial satellites, and debris." (*Benchmarks*, page 64.) And by the end of high school, "the role of gravity in forming and maintaining planets, stars, and the solar system should become clear." (*Benchmarks*, page 64)

Activities 1-3 provide opportunities for students to thoroughly explore the concepts of the spherical Earth and gravity. In Activity 4, students observe a planet other than Earth. In Activity 5 they learn about orbits. Activities 6-8 are concerned with our neighbors, Venus and Mars. Activities 9-11 provide fun contexts for students to become familiar with all nine planets in our solar system; and Activity 12 is about the different gravitational pull that we would experience if we lived on another planet. See also the activities, "Invent an Alien" in the *Space Exploration and SETI* section, and "The 12 Tourist Wonders of the Solar System" in *Across the Curriculum* for more activities related to the planets.



BACKGROUND:
THE PLANETS

When the ancients studied the night sky, they noticed that five "stars" moved with respect to the others. They called them "planets," from the Greek word for "wanderer," and kept careful records of their motions. These records eventually enabled astronomers to figure out why they moved as they did: the planets, including our Earth, orbit around the Sun. Over the years, telescopes have revealed the existence of three other planets, too faint to have been seen by the ancients, bringing the total number to nine (including Earth).

The planets basically come in two different types. The Earth-like, or "terrestrial," planets—Mercury, Venus, Earth and Mars—are small, dense, rocky worlds. They all have solid surfaces, and all are located in the inner part of the solar system. Mercury, closest to the Sun and smallest of the terrestrial planets, has no appreciable atmosphere. Venus, a near twin in size to the Earth, has a very thick atmosphere composed of primarily carbon dioxide gas, with surface air pressures 90 times greater than those on Earth. The thick air traps heat from the Sun, in much the same way greenhouses keep warm despite cold temperatures outside; temperatures at the Venusian surface are over 800° F. If you're ever unfortunate enough to land on Venus, you could be almost simultaneously asphyxiated, crushed and burned up the instant you step out of your spaceship!

Mars, also has a carbon-dioxide atmosphere, but it is extremely thin, only about one percent as thick as Earth's. The thin air doesn't retain heat well, and surface temperatures range from a frigid -220° F on a cold, winter night to 70° F at the equator on a hot, summer day. Mars has polar ice caps, and what look like dry streambeds, leading many researchers to surmise that at some time in the very distant past, Mars may have had a thicker atmosphere and running water on its surface.

Unlike the terrestrial planets, Jupiter and the other "Jovian" planets in the outer solar system—Jupiter, Saturn, Uranus and Neptune—have no solid surface on which you can stand. They are gas giants; large (eleven Earths could fit across Jupiter's equator), rapidly rotating, with very low-density. Saturn's density, in fact, is so low that if you had a bathtub large enough filled with water, the planet would float! When we look at the Jovian planets, we see the tops of clouds. All show complicated wind patterns and immense "storm centers"—like Jupiter's famous Great Red Spot—except for Uranus, which has an almost featureless cloud deck (perhaps because its interior is cooler than the other Jovian planets). As you go deeper into their atmospheres, the gases get thicker and thicker, until finally they turn into a liquid. At their centers, is an Earth-sized rocky core.

Unlike the terrestrial planets, the Jovian giants are circled by rings of icy particles. Saturn's is, by far, the most beautiful—an extensive, complex system of billions of tiny particles orbiting Saturn's equator. The others' rings are much thinner and fainter. Astronomers think the rings are debris, perhaps from collisions involving their moons, captured by the giant planets' gravity. Each of the Jovian planets has many moons; several (Jupiter's Ganymede and Callisto, and Saturn's Titan) are at least as big as, if not bigger than, the planet Mercury!

Tiny Pluto, the smallest planet (it's only about 2/3 the size of Earth's Moon) and most distant from the Sun, doesn't really fall into either the terrestrial or Jovian categories. Like a terrestrial planet, it is small, but, because it's a mixture of rock and ice, its density is low, like a Jovian planet. It's not a gas giant, but it is in the outer part of the solar system. Because of its small size and eccentric orbit, researchers used to think Pluto might be an escaped moon of Neptune's. But when they found that Pluto has its own moon (that's almost half its size), that simple idea fell out of favor. Now astronomers think Pluto and some of the other icy moons and comet-like objects also found out past the orbits of Neptune and Pluto may be all that's left of a large number of small, icy bodies that once filled the outer solar system. Most of these bodies probably became part of the giant planets or were flung into the far fringes of the solar system by close encounters with the Jovian planets' strong gravities.

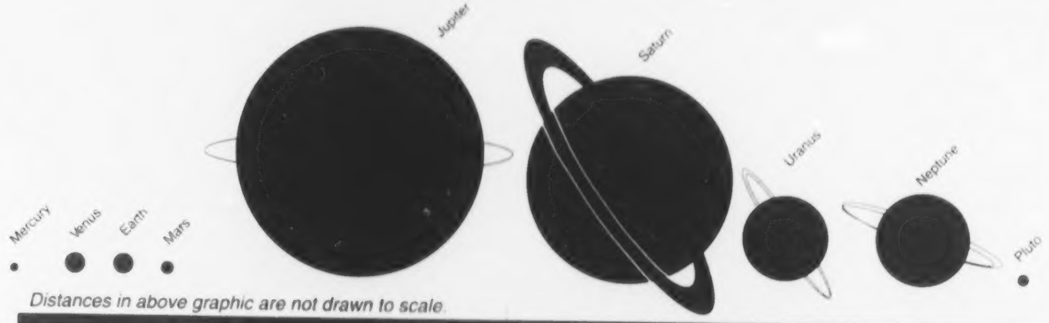
These encounters most likely occurred early in the life of the solar system. Astronomers think the planets formed at the same time as the infant Sun, about 4.6 billion years ago, as a giant cloud of interstellar gas and dust contracted. Most of the material fell into the center of the cloud, becoming the Sun, but (to simplify a complicated story) some was left behind in a disk circling the young star. Over time, small grains of dust in the disk collided and stuck together. As they grew larger, they pulled nearby material toward them, increasing their size even more. Eventually they became large chunks, which collided and merged together, until planet-sized objects existed. The planets then "swept up" the remaining material, pulling the leftover gas and dust toward them, leaving the space between the planets largely empty.

This scenario for the formation of the planets helps explain observed similarities between them. All the planets revolve around the Sun in the same direction (counterclockwise, as seen from above the north pole of the Sun), and with the exception of Venus and Uranus, all rotate on their axis in a counterclockwise direction. In addition, all the planets circle the Sun in very nearly the same plane. All this can be explained because the planets formed out of the same rotating disk.

The scenario can also explain their differences, primarily why the terrestrial planets are small and rocky, while the Jovian ones are gassy giants. In the inner part of the solar system, heat from the Sun made it too hot for most of the gas in the disk to condense into a solid. Only small amounts of high-density materials like rock and metals could condense, resulting in small, rocky planets. Farther out in the disk, temperatures were cool enough that a lot of ice formed. Thus the outer planets grew quickly, enabling them to become quite big. When they got sufficiently large, they pulled vast amounts of gases like hydrogen and helium toward them, providing the extensive gaseous atmospheres in these planets. The terrestrial planets never got large enough, and the temperature in the inner parts of the disk was too high, to trap the same gases.

According to this scenario, planets should form as natural by-products during the birth of stars. This leads astronomers to think that many stars may be accompanied by planetary systems. So far, no planet has been seen around another star, in part because they are so small and faint that they're hidden by the glare from their parent stars. However, astronomers have seen large disks of dust around young stars, such as Beta Pictoris. These stars may be in the process of forming planets. If other stars do have planets, we may not be as alone in the universe as we think.

Charting the Planets



Distances in above graphic are not drawn to scale.

Categories	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
1. Mean Distance From Sun (Millions of Kilometers)	57.9	108.2	149.6	227.9	778.3	1,427	2,871	4,497	5,914
2. Period of Revolution	88 days	224.7 days	365.3 days	687 days	11.86 years	29.46 years	84 years	165 years	248 years
3. Equatorial Diameter (Kilometers)	4,880	12,100	12,756	6,794	143,200	120,000	51,800	49,528	~2,330
4. Atmosphere (Main Components)	Virtually None	Carbon Dioxide	Nitrogen Oxygen	Carbon Dioxide	Hydrogen Helium	Hydrogen Helium	Helium Hydrogen Methane	Hydrogen Helium Methane	Methane + ?
5. Moons	0	0	1	2	16	18	15	8	1
6. Rings	0	0	0	0	3	1,000 (?)	11	4	0
7. Inclination of Orbit to Ecliptic	7°	3.4°	0°	1.9°	1.3°	2.5°	0.8°	1.8°	17.1°
8. Eccentricity of Orbit	.206	.007	.017	.093	.048	.056	.046	.009	.248
9. Rotation Period	59 days	243 days Retrograde	23 hours 56 min.	24 hours 37 min.	9 hours 55 min.	10 hours 40 min.	17.2 hours Retrograde	16 hours 7 min.	6 days 9 hours 18 min. Retrograde
10. Inclination of Axis*	Near 0°	177.2°	23° 27'	25° 12'	3° 5'	26° 44'	97° 55'	28° 48'	120°

* Inclinations greater than 90° imply retrograde rotation

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THE EARTH'S SHAPE AND GRAVITY

ACTIVITY C-1

GRADE LEVEL: 4-9

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What's This Activity About?

If the Earth really is a sphere in space, how do people at the "bottom" stay on? Answering this question leads us to explore how gravity works, and this GEMS Guide activity is an outstanding example of how to stimulate critical thinking. As students begin to examine and compare planets, moons, asteroids, and comets in the solar system, they will quickly notice shapes. The smallest bodies come in a great variety of non-uniform shapes, but soon students will notice all larger bodies become quite spherical. Gravity is the key to the shapes of planets, and to how our solar system "holds together."

What Will Students Do?

Students investigate their ideas about how gravity works. Students start by discussing how they think the Earth is shaped and how things fall here and at different places around the planet. Students then discuss how gravity works as a global force.

Tips and Suggestions

- Ask students how they think falling and gravity work on other objects in the solar system, like Jupiter or a small oblong asteroid?
- The last question (about dropping something into an imaginary hole dug completely through the Earth) can be related to some wonderful inquiries into physics. Relate the activity to the concepts of falling (acceleration), forces (gravity), and even harmonic motion (like pendulum or spring motion).
- Pictures of people in Chile, Australia, or at the South Pole will help to stimulate discussion about what is "down."

What Will Students Learn?

Concepts

Gravity
Falling
The shape of the Earth

Inquiry Skills

Observing
Relating
Communicating
Inferring

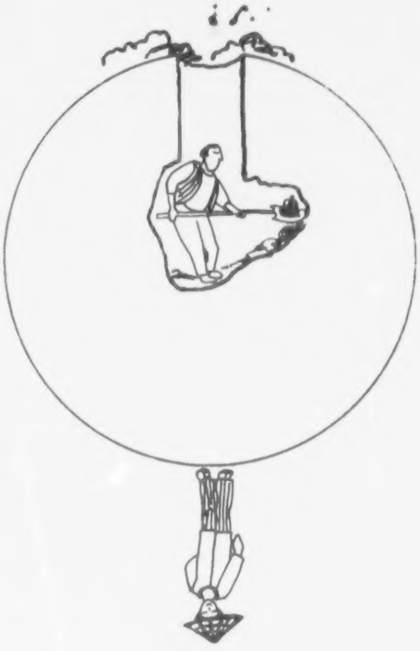
Big Ideas

Scale
Systems and Interactions

Activity 2: The Earth's Shape and Gravity

Introduction

Despite the evidence of our senses, we are told as early as the first and second grades that the Earth is really shaped like a ball, that the Earth is round. Perhaps you also remember someone telling you that you could "dig a hole all the way to China," or that people in faraway nations lived "down under your feet, on the other side of the world."



These statements seem unbelievable to us at first, but they are consistent with what we learn in school about the ball-shaped Earth. These early childhood memories provide our first conceptual suggestions about what a ball-shaped Earth implies. As such, they are truly significant learning experiences.

In this activity, a questionnaire launches your students on animated discussions about the implications of the ball-shaped Earth model, which in turn helps lead to a deeper understanding of gravity.

When you lead discussions with your students, please keep in mind that ideas and insights about the Earth's shape and gravity develop gradually. **Getting the "right answer" is not as important as the critical thinking skills that students develop as they struggle to apply their mental models of the Earth to real and imaginary situations.**

Time Frame

Part I: What Are Your Ideas?	30 minutes
Part II: Discussion	40 minutes

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What You Need

For the class:

- ☐ 8 copies of the "What Are Your Ideas About Earth?" questionnaire (master included, page 14)
- ☐ 8 Earth globes or other large balls
- ☐ 8 bowls or rolls of tape (to support globes)

For each student:

- ☐ 1 copy of the "What Are Your Ideas About the Earth?" questionnaire

Getting Ready

1. Copy the questionnaire, making one copy for each student, plus eight additional copies.

2. Borrow eight Earth globes, or obtain beach balls, basketballs, or other large balls to represent the Earth. Remove the globes from their stands, and place them on bowls or rolls of tape, so they will not roll of the tables.

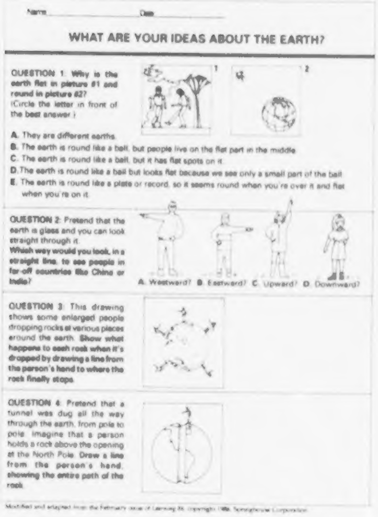
Part I: What Are Your Ideas?

1. Hand out copies of the questionnaire. Ask your students to write their names at the top of their papers and to answer the questions. Allow 10 to 15 minutes for the students to finish. Collect the students' papers so you can look over their ideas later.

2. Organize the class into eight discussion groups of three to five students per group. Explain that each team is to discuss the questions and come to an agreement, if possible, on the best responses.

3. Give each group an Earth globe and one blank questionnaire to use for recording their final answers.

4. Circulate among the groups of students, encouraging them to discuss any disagreements fully and to use the globes to demonstrate their ideas. Groups who agree on the answers early should be instructed to make a list of arguments in support of their answers.



Name ______________ Date ______________

WHAT ARE YOUR IDEAS ABOUT THE EARTH?

QUESTION 1: Why is the earth flat in picture #1 and round in picture #2? (Circle the letter in front of the best answer.)

A. They are different earths.
B. The earth is round like a ball, but people live on the flat part in the middle.
C. The earth is round like a ball, but it has flat spots on it.
D. The earth is round like a ball but looks flat because we see only a small part of the ball.
E. The earth is round like a plate or record, so it seems round when you're over it and flat when you're on it.

QUESTION 2: Pretend that the earth is glass and you can look straight through it. **Which way would you look, in a straight line, to see people in far-off countries like China or India?**

A. Westward? B. Eastward? C. Upward? D. Downward?

QUESTION 3: This drawing shows some enlarged people dropping rocks at various places around the earth. **Show what happens to each rock when it's dropped by drawing a line from the person's hand to where the rock finally stops.**

QUESTION 4: Pretend that a tunnel was dug all the way through the earth, from pole to pole. Imagine that a person holds a rock above the opening at the North Pole. **Draw a line from the person's hand, showing the entire path of the rock.**

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Part II: Discussion

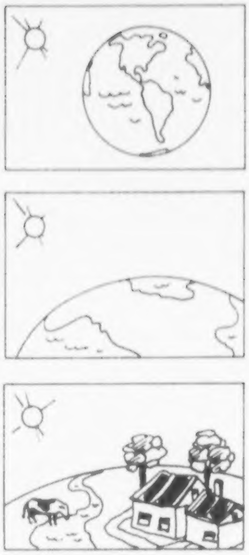
1. Lead the class in a discussion about the questionnaire. Play the role of moderator, requiring each group to support their ideas with arguments or to demonstrate using the Earth globes.

2. After discussing one question, poll the students on the alternative answers. Do not announce the correct answers at this time; students should be encouraged to think for themselves.

3. Following is a description of the kinds of answers you can expect from your students and some suggestions for facilitating the discussion:

Question 1. The correct answer is: "d. The Earth is round like a ball, but looks flat because we see only a small part of it."

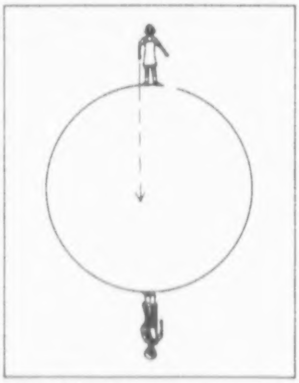
You can expect some variation in your students' ideas on this question, since it requires a correct understanding of the part-to-whole relationship between the "flat ground" of our everyday experience, and the "ball-shaped Earth" that we learn about in school. For example, one student thought that the Earth we live on is really flat, and the ball-shaped Earth is "a planet in the sky, where only astronauts go."



Question 1.

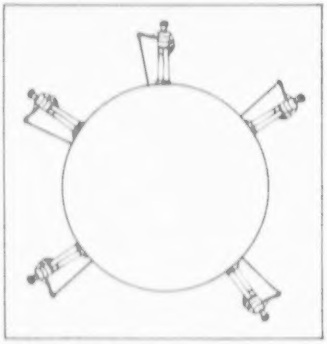
Question 2. The correct answer is: "d. Downward."

When first confronted with this question, most people try to imagine which direction they would fly in a plane to get to Australia, and will answer, "eastward" or "westward." Ask your students to imagine that the Earth is made out of glass and that they can look straight through it. You might also use a globe and a ruler to show what happens if you look due east or west: the ruler (representing the way you would look) points off into space.



Question 2.

Question 3. The correct answer shows each rock falling straight down, landing next to the person's feet. It is common for students to show the rocks falling off the Earth, to an absolute down direction in space, or to compromise the two views by showing the rocks falling at an angle.



Question 3.

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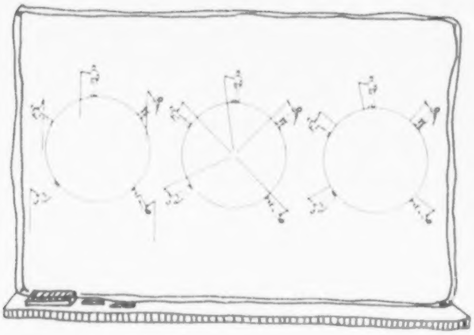
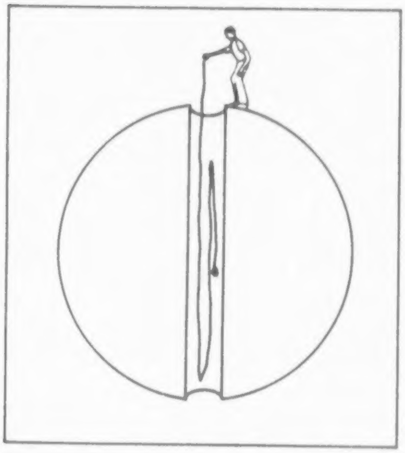
To help the students discuss their answers to this question, draw three or four large circles on the board, each with figures holding rocks as shown on the questionnaire. Invite students to come up to the board to draw their answers. The pictures of three or four alternative views will help you focus the discussion on which answer is best.



At some point in the discussion, you may need to explain why "down" is always toward the center of the Earth. Ask your students to think about the people who live all around the ball-shaped Earth. The only way to explain why these people do not fall off is to imagine that "down" is toward the center of the Earth. To demonstrate this idea, turn an Earth globe so that the South Pole is "up" and ask the students to imagine being there. People on the South Pole must think that people in the Northern Hemisphere live upside-down!

Question 4. This one stumps many adults! The best way to explain what occurs is to explain the history of the concept of ***gravity*** in this way:

When the ancient Greeks came up with the idea of a ball-shaped Earth, they had to explain why people who lived on the other side of the world didn't fall off. Aristotle, who lived about 2,300 years ago, thought that everything went to its "natural resting place" in the center of the universe, which he believed to at the center of the Earth. If Aristotle had filled out the questionnaire, he would have drawn a line to the center and stopped there.



The idea was revised "only" about 300 years ago by Isaac Newton, who believed that the rock falls because of a pulling force between every particle within the Earth and every particle within the rock. He named the force ***gravity***. From the rock's point of view, "down" is always toward the greater mass of the Earth. Before it reaches the center of the Earth, the rock keeps going faster and faster because it is still falling "down." It only starts slowing after it passes the center, because then the greater mass of the Earth is behind it. If Isaac Newton were to fill out the questionnaire, he would draw the rock falling back and forth between the two poles of the Earth, until air resistance finally slowed it down. Eventually, it would settle in the exact center of the Earth, suspended in the middle of the tunnel.

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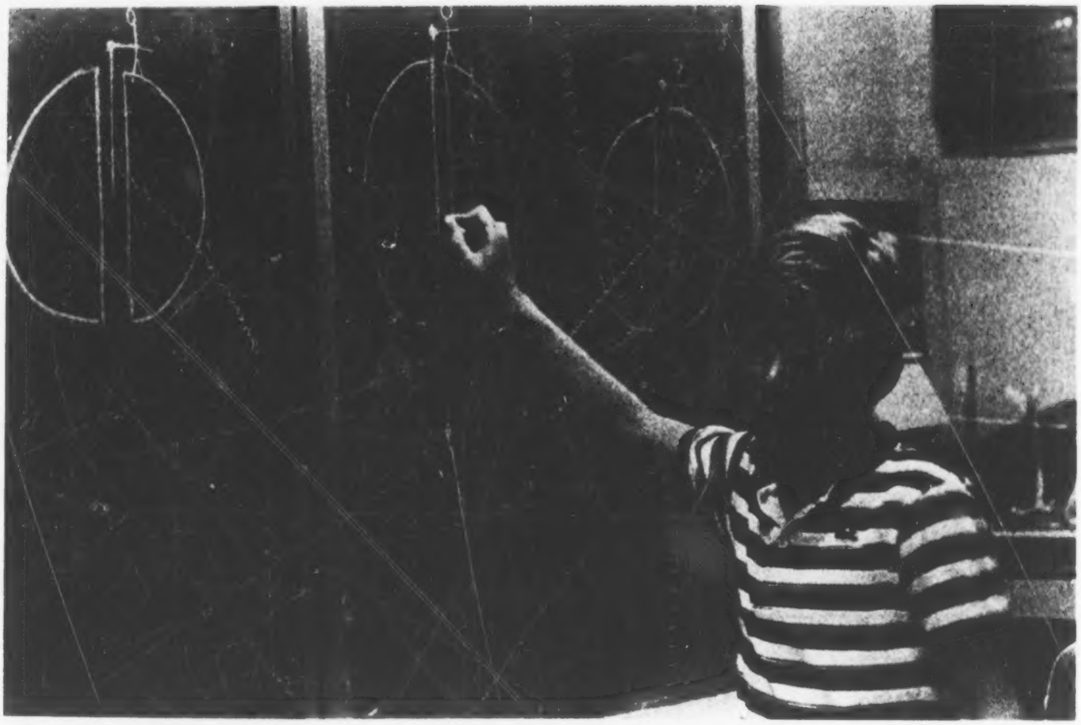

Again, it is helpful to draw several circles on the board, showing the figure and tunnel in each one. Invite students to come up and draw their answers until several different ideas are represented. Then lead a discussion debating the merits of each idea.

4. After the discussion, give the correct answers, as outlined above, as "the opinion of most scientists."

5. To evaluate this activity, have your students complete the questionnaire again, two or three weeks later.

Research on how students gain understanding of the Earth's shape indicates that the learning process is a gradual one. The questionnaire can be used to construct a class "profile" and determine levels of understanding to help guide appropriate Going Further activities. See pages 53–54 of this guide for suggestions on how to do this.

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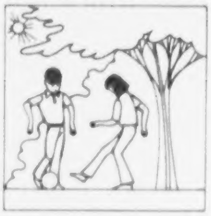
Name______________________ Date______________

WHAT ARE YOUR IDEAS ABOUT THE EARTH?

QUESTION 1: Why is the Earth flat in picture #1 and round in picture #2? (Circle the letter in front of the best answer.)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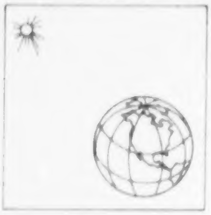
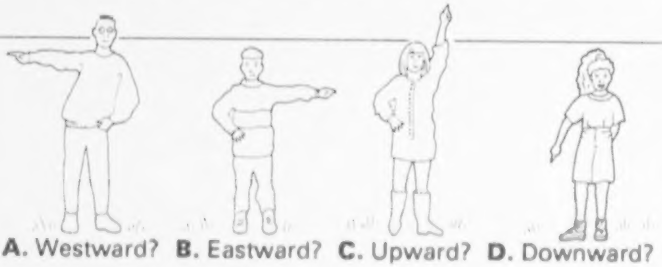
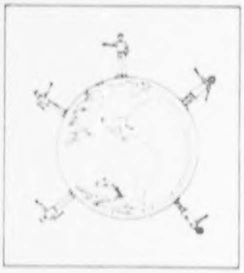

2

A. They are different Earths.
B. The Earth is round like a ball, but people live on the flat part in the middle.
C. The Earth is round like a ball, but it has flat spots on it.
D.The Earth is round like a ball but looks flat because we see only a small part of the ball.
E. The Earth is round like a plate or record, so it seems round when you're over it and flat when you're on it.

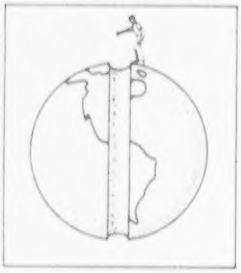
QUESTION 2: Pretend that the Earth is glass and you can look through it. **Which way would you look, in a straight line, to see people in far-off countries like China or India?**


A. Westward? **B.** Eastward? **C.** Upward? **D.** Downward?

QUESTION 3: This drawing shows some enlarged people dropping rocks at various places around the Earth. **Show what happens to each rock by drawing a line showing the complete path of the rock, from the person's hand to where it finally stops.**



QUESTION 4: Pretend that a tunnel was dug all the way through the Earth, from pole to pole. Imagine that a person holds a rock above the opening at the North Pole. **Draw a line from the person's hand showing the entire path of the rock.**



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WHAT SHAPE IS THE EARTH?

ACTIVITY C-2

GRADE LEVEL: 7-9

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What's This Activity About?

Our students have grown up in a world where images of the Earth taken by satellites and spacecraft clearly show the planet to be spherical. These pictures are so commonplace that students may not even consider that their local "flat" horizon could seem to indicate that the Earth is flat. This activity shows how ancient peoples around the world might have realized that our Earth was "round" through observation and deductive reasoning.

What Will Students Do?

Students compare the length of shadows from nails arranged on a flat map compared with nails arranged around a spherical globe. From their observations, they infer that different shadow lengths at different locations would clearly indicate that our planet is not flat.

Tips and Suggestions

- Students may take for granted that the Earth is round, so challenge them to imagine living 2,000 years ago in a time before satellite weather images and pictures from space.
- Some other ways to show that the Earth is round include: seeing that the Earth always makes a round shadow on the Moon during an eclipse, watching how ships with tall masts disappear below the horizon, and noting how the altitude of a well known group of stars (like the Big Dipper) changes as you go north or south.
- One wonderful extension to this activity, especially for older students is to divide the class into groups, and ask: "How would you prove today, if money were no object, that the Earth is round?" Each group should come up with three different proofs and share their suggestions.

What Will Students Learn?

Concepts	**Inquiry Skills**	**Big Ideas**
Spherical nature of Earth	Observing	Models
Shadows created by different shapes	Comparing	Interactions
	Visualizing	
	Imagining	
	Reasoning	

What Shape Is the Earth?

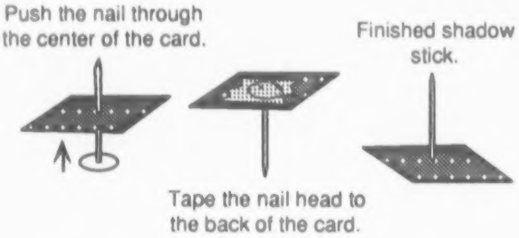
For nearly 2000 years before Columbus, people knew that the Earth was shaped like a ball. No one knows who first proposed this idea, but Pythagoras of Samos may have suggested it about 500 B.C. The idea was strongly supported by Aristotle. In about 350 B.C. Aristotle mentioned the disappearance of ships over the horizon, the Earth's round shadow on the moon during an eclipse, and the changing positions of stars as a person travels southward. Unlike modern scientists, however, Aristotle believed that the Earth must be a sphere, because a sphere is a perfect shape!

In this activity, your students will explore one very important line of evidence, known in Ancient Greece, that supported the idea that the Earth is shaped like a ball. They will see that shadows of vertical sticks, placed at different locations around the Earth, have different lengths at the same time. This particular argument for the ball-shaped Earth premise lays the foundation for the next activity in which the students measure the Earth's circumference.

Before the Lesson

Materials

- ☐ 1 large globe of the Earth without the cradle (at least 12" in diameter)
- ☐ 1 large flat map of the world
- ☐ 12 nails with large, flat heads about 1-2" long
- ☐ 12 pieces of stiff stiff paper, 1" x 1" cut from index cards
- ☐ 1 pair of scissors
- ☐ 1 roll of masking tape
- ☐ 1 ruler
- ☐ A sunny day


Push the nail through the center of the card.
Finished shadow stick.
Tape the nail head to the back of the card.

Preparation

1. Make 12 shadow sticks by pushing the nails through the centers of the 1" x 1" pieces of stiff paper and taping the nail heads to the backs of the cards. For extra safety, blunt the ends of the nails with a file.

2. Make a few masking tape loops, with the sticky side out, so that the shadow sticks can be attached to the globe and flat map.

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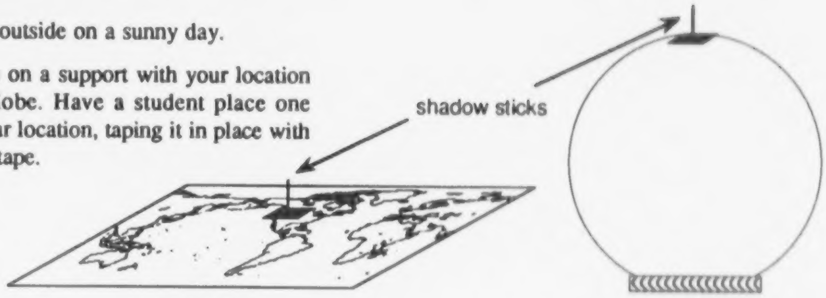
Part A. Shadows Around the Earth

1. Take your class outside on a sunny day.

2. Set up the globe on a support with your location on "top" of the globe. Have a student place one shadow stick at your location, taping it in place with a loop of masking tape.



World Map **World Globe**

3. Place the flat map of the world on the ground nearby. Have another student place a shadow stick at your location on the flat map and hold it in place with tape.

4. ***Ask a third student to use the ruler to measure and compare the lengths of the two shadows.***

5. Form a team of students to place five or six shadow sticks on the globe with tape in various sunny locations all over the world. ***Ask them to measure and compare the shadows. Are they the same, or different, and why?*** *(The shadows are different lengths because the globe is round.)*

6. Form another team of students to place five to six shadow sticks on the flat map of the Earth at the same locations as on the globe. ***Ask them to measure and compare the shadows. Are they the same, or different, and why?*** *(Approximately the same because this map of the world is flat.)*

7. Ask the students if their observations of shadows on the globe and flat map suggest a way to determine if the Earth is really flat, or round like a ball. *(We could have people in cities all around the world measure the lengths of shadows from vertical sticks of the same size. Then they call each other on the telephone. If the shadows are the same, the Earth is flat. If the shadows are different, the Earth is round!)*

Part B.
Finding the "No Shadow" Place

1. Have students experiment with the shadow sticks to find a place on the sunny side of the globe where there is no shadow cast by the nail. When the place is located, tape the shadow stick to the globe. It marks the place where the Sun is directly overhead at that moment in time.

2. Find the same place on the flat map, and compare the shadow on the flat map with the lack of shadow on the globe.

3. Try to find the "no shadow" place on the flat map of the Earth. The shadows on the flat map of the Earth will all be the same. The students will not be able to find a "no shadow" place on the flat map of the Earth.

4. Explain to your students that the varying lengths of shadows on the globe demonstrate what is observed on the real Earth. It is evidence that the Earth is round. Today we define the tropics as the portion of the world where there is at least one "no shadow" day each year when the Sun passes directly overhead at local noon. The next activity, How Big Is the Earth?, allows students to apply these concepts to measure the size of the Earth.

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HOW BIG IS THE EARTH?

ACTIVITY C-3

GRADE LEVEL: 8+

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What's This Activity About?

Often in science we fall into the habit of stating results as facts, without giving students the opportunity to investigate how we discovered those facts. The size of our planet is a classic example, as is measuring the approximate sizes and distances of other objects in the solar system. This activity simulates Eratosthenes' geometry experiment with shadows in Egypt in which he determined the approximate size of our planet. It is a wonderful lesson in science and in history!

What Will Students Do?

Students read about Eratosthenes' idea, and follow his reasoning and calculations to estimate the size of our planet based on the evidence he collected.

Tips and Suggestions

The level of your student's mathematical skills must be considered before you do this activity. Tying this exercise to shadow observations (found in activities in the *Sun and Seasons* section) will help students make the connection between Eratosthenes' evidence and his calculations.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Basic geometry	Calculating	Scale
Ratios	Inferring	
Spherical approximation of Earth		

How Big Is the Earth?

In about 300 B.C. Eratosthenes, a librarian in Alexandria, Egypt, discovered how to measure the circumference of the Earth. This is one of the most astonishing achievements of ancient science. Only about 50 years after Aristotle described the evidence that supported the idea that the Earth is shaped like a sphere, Eratosthenes figured out how to measure its circumference. In this activity, your students will discover Eratosthenes' reasoning. Based on the evidence that Eratosthenes had available, they will calculate the Earth's circumference.

We suggest that you take into account the level of math understanding of your students. While making the calculation is easy, understanding the reasoning requires geometry skills. High school geometry students should have little difficulty. If you plan to introduce the activity with younger students, it is advisable first to introduce the two major mathematical concepts on which the activity depends: (1) You can measure the angle of a shadow formed by a stick as a fraction of a circle; and (2) Parallel lines cut by a straight line create equal angles.

Materials/Preparation

- ☐ Copy activity sheets for each student, using masters on pages 39 and 40: *How Big Is the Earth?—Part 1* and *How Big Is the Earth?—Part 2*
- ☐ Optional: 1 calculator per student

In Class — Eratosthenes' Method of Measuring the Earth

1. Ask your students to recall the previous activity, in which they learned one reason why people believed over 2,000 years ago that the Earth is shaped like a ball. Ask if anyone can suggest how to measure the size of the ball-shaped earth. (Accept all answers.) Explain that in ancient times it was not possible to travel all the way around the Earth or into space. Nonetheless, a very intelligent librarian was able to figure out how large the Earth was.

2. Divide the class into teams of two or three students. Hand out the two activity sheets one at a time, allowing time for the students to read and discuss them in teams. Then lead a class discussion, answering questions as necessary. When discussing the distance between Alexandria and Syene, you may want to note that there is some dispute about the length of the unit of measurement (stadia) that Eratosthenes used in 300 B.C. According to J.L.E. Dryer, *A History of Astronomy from Thales to Kepler*, the most likely value of the Earth's circumference calculated by Eratosthenes was 24,662 miles. The modern value for the Earth's circumference is about 24,900 miles.

3. In conclusion, ask your class to imagine taking a 24,900 mile trip in a straight line on the surface of the Earth. They would travel in a great big circle all the way around the Earth and return to the same place! Eratosthenes knew this almost 2,300 years ago. Christopher Columbus did not have to prove that the Earth was shaped like a ball.

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How Big Is the Earth? — Part 1

"My name is Eratosthenes. I'm a Greek scientist and librarian in the great library in Alexandria, Egypt. I have figured out a way to measure the distance around the ball-shaped Earth. Let me show you how you can do it too."

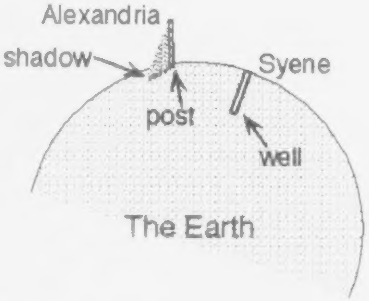
"I have read that at noon on the longest day of the year, the Sun's light shines directly down a well in Syene, a city that is several hundred miles to the south. (Locate Syene on the cross-section of the Earth on this page.) When I look at a vertical post in Alexandria at noon on the longest day of the year, the Sun's rays cast a shadow 1/8 the length of the post."

1. In the picture, draw the Sun, and show where it must be in order to shine directly down the well at noon in Syene ***and*** create a shadow in Alexandria.

2. If you see a vertical post in Syene at the same moment as the Sun shines directly down the well, does the post cast a shadow?

______yes ______no

3. Why do we see a shadow cast by the post at noon in Alexandria at the same time we see no shadow in Syene? What does this tell me about the shape of the Earth?



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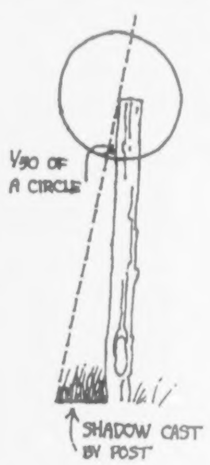
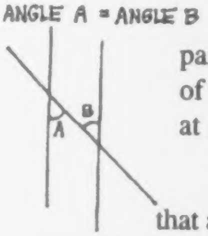
How Big Is the Earth? — Part 2

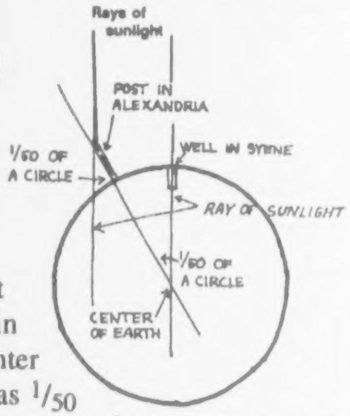


Eratosthenes continues his story.

"One of my favorite books is about geometry, written by Euclid. It helped me find out how big the Earth is. At noon on the longest day of the year in Alexandria, the length of a shadow cast by a post was about 1/8 the length of the post. From Euclid's geometry, I found that the angle at the top of the post must have been about $^1/_{50}$ of a circle."



"From Euclid I also learned that if I draw two parallel lines with one straight line crossing both of them, certain angles are equal. In the drawing at left, angle A = angle B."



"One day I read a book which said that at noon on the longest day of the year, the sun shines straight down a well in Syene, several hundred miles south of Alexandria. Since the Sun is very far away, a ray of sunlight that reaches Alexandria is parallel to a ray of sunlight that reaches Syene."

"When I drew a diagram of the Earth I realized that the angle of the shadow cast by the vertical post in Alexandria equals an imaginary angle formed by the center of the Earth, Alexandria and Syene. Since that angle was $^1/_{50}$ of a circle, the distance between Alexandria and Syene must be $^1/_{50}$ of the distance around the Earth."

"Then I paid someone to measure the distance from Syene to Alexandria by walking from one city to the other, and counting his steps. He measured the distance to be 5,000 stadia [about 493 miles in modern terms]."

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How Big Is the Earth? (give answers on the back of the paper)

1. If 493 miles (793 km) is $^1/_{50}$ of the way around the world, how many miles is it all the way around the world? (Show your calculations.)
2. What is the circumference of the world by modern measurements? (Look it up!) How close was Eratosthenes' calculated measurement to the modern measurement?

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Key for *How Big Is the Earth—Part 1*

1. The Sun is directly overhead—straight over the city of Syene and the well.

2. When the Sun is directly overhead (see #1), a vertical post will not cast a shadow because the Sun is also directly over the post.

3. Eratosthenes sees a shadow in Alexandria because the Sun is not directly overhead in Alexandria. Alexandria is 493 miles (793 km), or about 7 degrees of latitude north of Syene, and the Sun can be directly overhead at only one place on the Earth at a time. Further, on a particular date, the Sun is directly overhead at noon for only one latitude around the globe, so places north and south of each other can never have the same shadow lengths at the same moment in time.

The Earth is shaped like a ball, and Eratosthenes knew it because there was a shadow from a vertical post at noon in Alexandria on the same day when there were no shadows at noon in Syene, a city south of Alexandria. On a flat Earth, all of the shadows would be the same at the same time of the day (in this case at noon).

Key for *How Big Is the Earth—Part 2*

How big is the Earth?

1. If 493 miles (or 793 km) is 1/50 of the way around the world, how many miles is it all the way around the world?

50 x 1/50 = 1 whole circumference of the Earth. So the problem is solved by taking 50 times the distance of 493 miles between Alexandria and Syene.

50 x 493 miles = 24,650 miles, or

50 x 793 km = 39,650 km

This is Eratosthenes' estimate of the circumference of the Earth.

2. What is the circumference of the world by modern measurements?

24,906 miles, or 40,074 km.

How close was Eratosthenes' calculated measurement to the modern measurement?

Modern circumference:	24,906 miles	40,074 km
Eratosthenes' circumference:	24,650 miles	39,650 km
The difference:	256 miles	424 km

For older students, you may wish to calculate the percentage of error, which may be found by dividing "the difference" by "the modern circumference":

256 miles ÷ 24,906 miles = .01 = 1% or
424 km ÷ 40,074 km = .01 = 1%

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OBSERVING A PLANET

ACTIVITY C-4

GRADE LEVEL: 4-9

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What's This Activity About?

One of the most common questions about astronomy is, "How do you know that 'star' is really a planet, and not a star? It looks just like a star." Without a telescope, it can seem impossible to someone unfamiliar with the constellations to tell the planets from the background stars. This simple activity shows how to tell the difference between stars and planets in our sky. Like other PASS activities, this was designed to be used with a planetarium. However, the concept of observing the sky over a period of time to identify "wanderers" is very important, and this activity can be done successfully in a classroom.

What Will Student's Do?

Students observe a series of constellation maps on a blackboard or overhead projector and identify the "wandering star." Then they complete the activity by going outside to simulate the motion of planets around the Sun in front of more distant background stars.

Tips and Suggestions

- Use a monthly sky chart from astronomy magazines such as *Sky & Telescope*, or annual calendars such as Guy Ottewell's *Astronomical Calendar* to match this activity to your local sky during a particular season. If bright planets like Venus or Jupiter are visible around sunset, you can ask older students to make pictures of what they see over two to three weeks.
- Investigate where or when particular planets are seen (Venus and Mercury are always seen around sunrise or sunset, while Mars, Jupiter and Saturn can be seen throughout the night). Why do we see some planets and not see others?
- Relate this activity to the history of astronomy in various cultures (the Greek celestial models, Ptolemy, the Mayan calendars based on Venus, the observations of Tycho Brahe).
- Link this activity with creating a scale model of the solar system.

What Will Students Learn?

Concepts

- Planetary motion
- Orbits
- Distances and time
  - (why we see planets move but not more distant stars)

Inquiry Skills

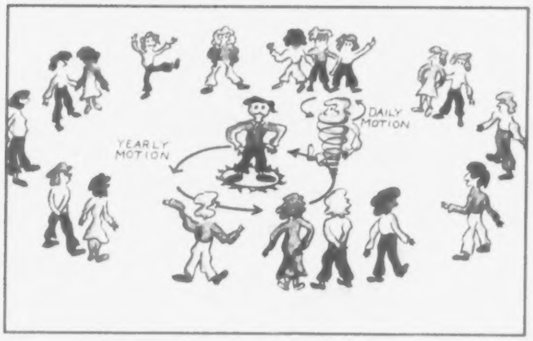
- Observing Systematically
- Inferring
- Visualizing
- Reasoning

Big Ideas

- Gravity

This science activity is designed for students in grades five through eight. It can be presented by teachers with no special preparation in science. SIMULATING THE SOLAR SYSTEM is keyed to some of the concepts in the planetarium program, "Red Planet Mars," so it will probably be most effective if presented just before or just after visiting the planetarium. Each teacher may wish to adapt the language and pace of the activities to his or her particular class of students.

Objectives



The primary objective of this activity is to increase the students' understanding of the appearance and movements of the stars and planets. After the lesson, the students will be able to explain or demonstrate:

1) What a planet looks like in the night sky.
2) How to find out if a given point of light in the night sky is really a star or a planet.
3) Why a planet appears to "wander" among the background stars.
4) How to use a model to figure out why the stars and planets appear to move as they do.

Before the Lesson

1) Arrange to move outdoors for the last part of the activity.
2) Draw three large boxes on the chalkboard. Use white or yellow chalk to draw stars in each of the boxes as shown on page 23. These drawings show the planet Saturn as it moves through the constellation Leo. All the stars should be the same size except for the bright star Regulus (in the lower right). Stars should be in the same positions in all three boxes except for the starlike object that is really Saturn (just above Regulus in the first picture). Another option which has the advantage of reusability is to make three large posters.
3) Cover the second two boxes with sheets of paper taped over them. If using posters, stack the three posters together on the chalk tray so Star Pattern #1 is showing, with Patterns #2 and #3 hidden behind it.

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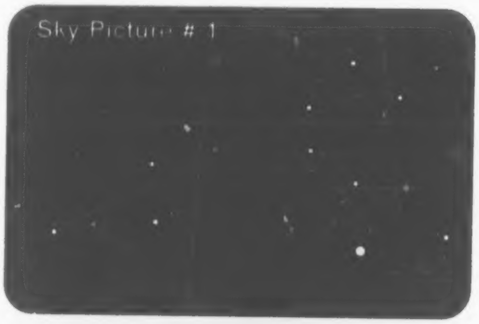
Part A. Observing a Planet

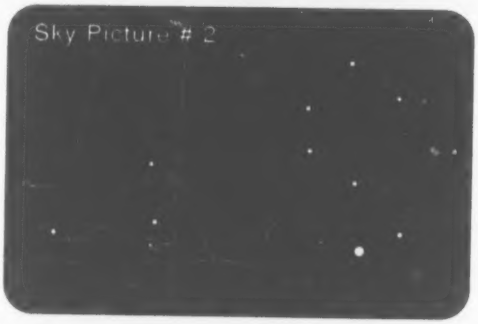
Stars and planets both look like points of light in the nighttime sky. Stars are huge hot balls of gas like the Sun. Planets are cooler balls of material like the Earth. Planets circle around stars in "orbits" and are almost always much smaller than stars. It takes the Earth one full year to complete its orbit around the Sun.

Here is a picture of the planet Saturn among the stars. ***Which one of these points of light do you think is Saturn?***



Direct students' attention to sky picture #1, and invite them to guess which dot is Saturn. Most students will guess the bright dot.

Hide picture # 1 and show picture #2.

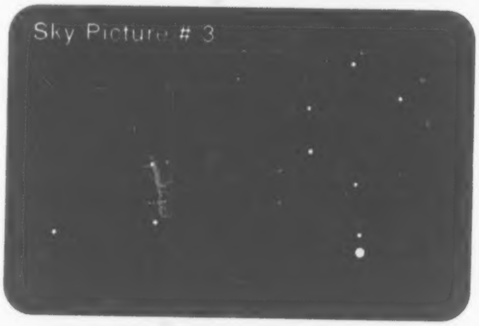


Here is another picture made one month later, showing the same part of the sky. ***Can you see anything different about it? Would you like to take a second guess about which one of these points of light is Saturn?*** Let's compare with last months picture side by side.

Expose pictures #1. and #2 side by side.

Where do you PREDICT Saturn will appear one month later?

Allow time for students to answer your question



Well, let's see if you are right.

Expose picture #3.

Here is how this pattern of stars appeared one month later. Who would like to describe how Saturn "wanders" against the background stars?

The planets appear to wander at different speeds and in different directions from month-to-month. Teachers who would like to learn more about these motions are encouraged to consult a "sky calendar" article in one of the many astronomy periodicals. Several good ones are listed in the section on periodicals in PASS Volume 3.

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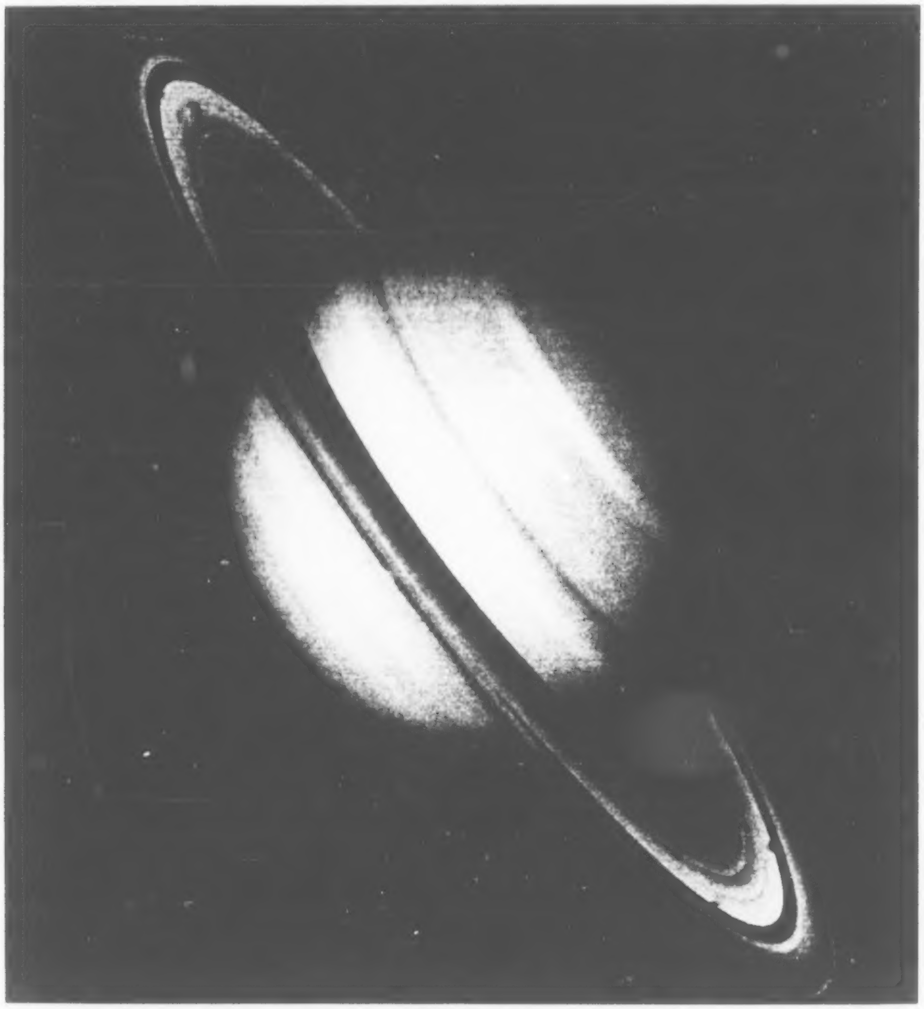
Through a telescope, a star appears very bright, but it is still just a point of light. A planet, however, is much closer to us, so we can see details on it. Let's look at this wandering point of light and see what it looks like through a telescope.

Point to the "star" that has changed its position. Show a poster, slide, or a picture of Saturn.



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Part B. Simulation Activity

Have the students go outdoors and stand in a large circle, about 40 feet in diameter (close enough to hear you).

Now we will do an activity to see why the planets seem to wander among the stars. First, we need two volunteers to stand in the center of our circle to play the parts of the Sun and Earth.

Have the Sun stand in the very center of the circle, and the Earth stand about five feet away.

Imagine that all of you in the circle are stars. Like the real stars, each of you has a name. If you want to appear even more like the stars, space yourselves around the circle so the Earth sees groups, or CONSTELLATIONS of stars.

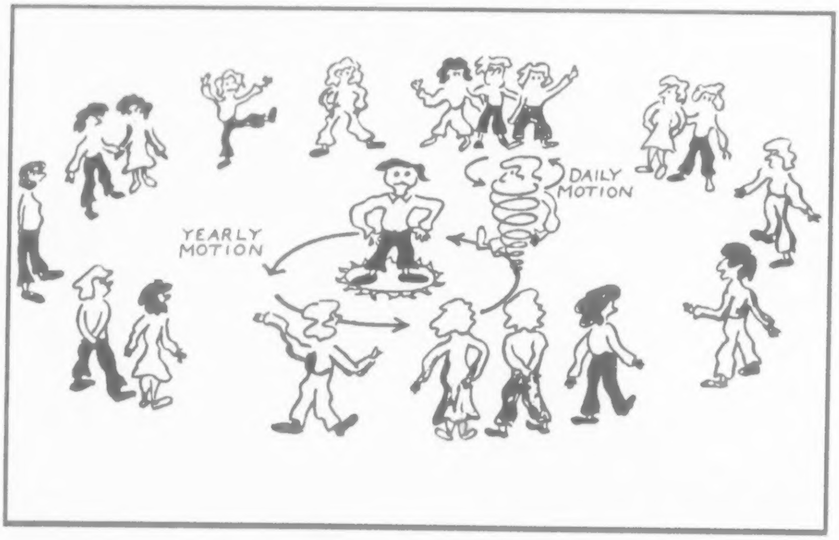
The students move a little closer or further apart so they are spaced unevenly around the circle. Optional: have the students hold signs which represent the various constellations.

Earth, please turn so you can see the Sun. What time of day is it for your face? (Noon.) Now turn so it is night for your face. Please point out some stars whose names you know!

The student playing Earth points to three or four classmates and says their names.

How should the Earth move so that a whole week of time goes by? How should the Earth move so that a whole year goes by?

At least one or two students in the class will probably be able to suggest that in one week the Earth would turn around seven times while standing in the same spot, or moving a bit along in its orbit.



To demonstrate a year, the Earth will have to walk around the Sun while at the same time spinning around.

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Earth, please demonstrate one year by walking all the way around the Sun in your orbit. If you get dizzy, we'll pretend you turned around 365 times as you walked in one complete circle.

Now I have a problem for you to figure out. I will divide the class into two groups. ***I want each group to make its own model of the Solar System, with the Earth, Sun, Stars, AND SATURN. You must decide where Saturn should be and how it should move. When we get back together again, I want each group to demonstrate why Saturn appears to "wander" against the stars. Any questions?***

Divide the class into two groups and assign areas for them to work in. Let the students choose who will play the Earth, Sun, and Saturn, and discuss how the planets should move. The students may want to know how long Saturn's day is (10 hours) or how long it takes for Saturn to go around the Sun (about 29 Earth years), but this information is not vital for this activity. Allow the teams to work until they have solved the problem (probably five to fifteen minutes.)

Come back and form a large circle again. ***Who would like to explain why Saturn appears to wander against the stars, while your teammates act out the Solar System?***

The students may discover either or both of the following explanations for why the planets appear to wander against the stars: First, the planets are VERY much closer to Earth than are the stars, so a slight change in the Earth's location will make planets appear to move with respect to the stars. Second, the planets are moving in their own orbits as well, so the direction an Earth observer must look to see another planet is always changing. It is not important for the teacher to explain these concepts in detail, but rather to let the students explain and demonstrate their ideas while the other students comment.

Now it's the second team's turn. ***Who is the explainer? The Earth? The Sun? . . . .***

Follow-Up Activities

1) Have the students extend their simulation of the solar system to include three, four, or even nine planets.

2) Have the students make a scale model of the solar system. We suggest the following procedure developed by Bob Risch and Jim Vickery, Co-Directors of the Jeffco Planetarium, Lakewood, Colorado, for their School District's Curriculum Guide. First, the students make models by selecting small objects to represent the planets. These can be taped to cards with cellophane tape and labeled. Then, the students can go out to the playground with measuring sticks to illustrate the distance scale of the solar system. They may be surprised at how much "space" there is in space! The scale recommended by the Jefferson County Curriculum Guide is printed on page 27 with permission of the developers.

3) Gerald Mallon of the Methacton School District Planetarium suggests a larger scale initially to compare the earth and sun. He uses a blue marble for the earth, and asks students to guess the size of the sun. The sun is then introduced as a 3-foot-diameter weather balloon! (Such balloons are available from Edmund Scientific Co., Barrington, New Jersey.)

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STAYING UP WHILE FALLING DOWN

ACTIVITY C-5

GRADE LEVEL: 7-9+

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What's This Activity About?

Once students have observed planets or our Moon in the sky, a natural question often arises: How do planets "stay up there"? The answer-gravity—may not at first make sense to students, but this activity will help them see the connection between gravitational force and orbital motion.

What Will Students Do?

Students will use a ball, string, and weight (a roll of tape), to simulate an object in orbit. Students observe the orbital radius shrinking and orbital velocity increasing by pulling on the weight. And students will investigate how orbital period (the time for one complete revolution), varies with the length of string.

Tips and Suggestions

- The activity correctly presents the force of the weight, transferred by the string, as a *centripetal*, or "center-seeking" force. It is important to use this term with students, to help them learn that the more common term "centrifugal" force is not responsible for orbital motion. To investigate the difference between centripetal and centrifugal force, encourage the students to cut the string, watch the motion of the ball, and predict its path. If an outward centrifugal force was acting on the ball, it should move *radially* away from the weight. Instead, the ball moves straight when the string is cut, demonstrating the *principle of inertia*: objects move in a straight line at constant speed unless acted on by a net force.
- Any kind of weight may be used instead of the roll of masking tape. If different weights are available, students can explore how fast they must twirl heavier weights compared with lighter ones. And, they can explore how different weights and string length affect orbiting speeds. Note that this activity simulates *circular* orbits. The actual planetary orbits are slightly elliptical. The principles of orbital speed, size, and force are the same.
- The activity does not demonstrate how the force of gravity decreases with distance. The introductory material for teachers states that "the most powerful gravitational force is exerted by black holes" but this is misleading. If our Sun were replaced with a black hole of the same mass (perhaps by angry aliens), the orbit of our planet would not change; we would feel the same force at the same distance. *Close* to a black hole, the gravitational force will be strong enough to prevent escape at speeds less than the speed of light.
- Also, asking students to draw representations of black holes, or developing metaphors, may be similarly misleading. The common, mistaken, impression is that a black hole is a "cosmic vacuum-cleaner," sucking in everything around it. This activity is a strong demonstration of centripetal force, and that is sufficient. You do not need to pull in the concept of black holes.

What Will Students Learn?

Concepts

- Gravity
- Centripetal force
- Orbits

Inquiry Skills

- Experimenting
- Exploring
- Observing
- Predicting
- Reasoning

Big Ideas

- Interactions
- Systems

Staying up while falling down

To demonstrate how a satellite stays in orbit by modeling the effects of Earth's gravity on a satellite and the Sun's gravity on the planets.

Participants demonstrate gravity acting as a centripetal force by threading a string through a straw and attaching a roll of tape (a gravitational force) to one end and a rubber ball (a satellite) to the other. As they hold the straw and swing the ball in orbit, the tape pulls on the string to keep the ball from flying off. In a second demonstration, they use ball and string combinations to represent the planets orbiting the Sun.

Materials Needed

- ★ 4-foot length of string
- ★ canvas sewing needle
- ★ small, soft rubber ball (about one inch in diameter)
- ★ plastic drinking straw
- ★ roll of masking tape

Strategies

The Earth's gravitational force is more powerful than the force of any object on the planet or any object near it in space, such as the Moon. The Sun's gravity is even more powerful than the Earth's or any other planet's. Other objects have even stronger gravity than the Sun.

The most powerful gravitational force is exerted by black holes. Not even light can escape the gravity of a black hole. Teens will probably have heard of black holes and be fascinated by them, even if they do not have much of an understanding of them. Stephen Hawking's *A Brief History of Time* provides an excellent overview of the subject from the world's leading authority. Have your group try their hand at drawing representations of black holes that demonstrate their understanding and/or by developing metaphors to describe their understanding (e.g., a black hole is like a _______ that ______).

The student activities are self-explanatory and should give teens a "feel" for the effects of gravity through relatively simple models. The concept can be difficult to grasp, and individuals might need to approach it in different ways. Some might want to express their understanding through an art form, for example, a way to involve teens who have learning styles that are more visual and auditory than those who do well with "paper/pencil" tasks. If possible, videotape the experiment so students can see the phenomenon over and over.

Extension

The activity sheet includes a challenge to students to develop and test a hypothesis about the relationship between the length of a planet's year and its distance from the Sun using different ball/string combinations. A chart that shows each planet's mean distance from the Sun is included.

Related Resources

Gravitator. Software (for IBM and compatibles) that calculates the gravitational forces on astronomical objects. Available from: Zepher Services, 1900 Murray Avenue, Pittsburgh, PA 15217.

Hawking, Stephen W. *A Brief History of Time: From the Big Bang to Black Holes.* New York: Bantam, 1988. (Also available on audiocassette from Dove Books on Tape, Inc., 12711 Ventura Boulevard, Studio City, CA 91604.)

Microgravity: An Operation Liftoff Project (computer software). 1985. Available from: Jet Propulsion Laboratory, Teacher Resource Center, Mail Stop CS-530, Pasadena, CA 91109.

Zee, A. *An Old Man's Toy: Gravity at Work and Play in Einstein's Universe.* New York: Macmillan, 1989.

Program	*1*	*2*	*3*	*4*	*5*	*6*
	★	★				★

Subject	*S*	*M*	*SS*	*T*	*LA*
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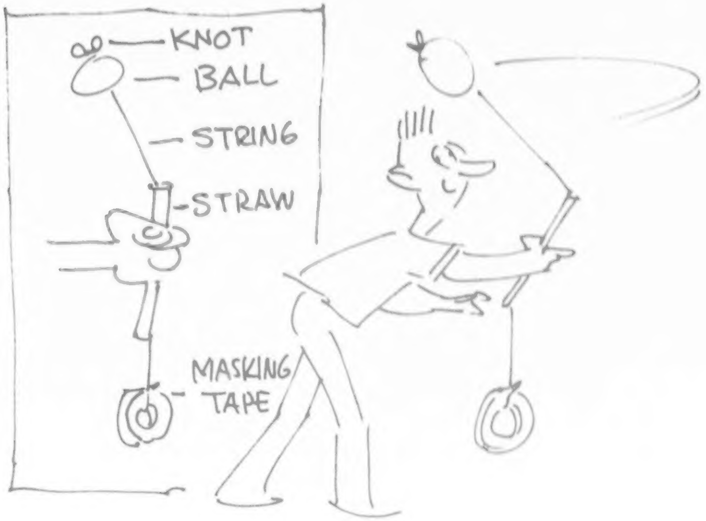
Staying up while falling down



Materials

- ★ ***4-foot length of string***
- ★ ***canvas sewing needle***
- ★ ***small, soft rubber ball (about one inch in diameter)***
- ★ ***plastic drinking straw***
- ★ ***roll of masking tape***

Demonstrate how gravity acts as a centripetal force. Using a canvas sewing needle, thread the string through the rubber ball. Tie a knot in the string on the outside of the ball. Thread the other end of the string through the straw and tie the roll of tape to that end. Hold the straw and swing the ball in a circle so that it "orbits" the straw. Be sure to keep moving your hand at a constant speed. The string acts as a centripetal force by preventing the ball from flying off.

What happens if someone pulls on the roll of tape to shorten the ball's orbit? Does the ball's speed change? What would happen if gravity did not exist, that is, if you cut off the tape?

Challenge

What does the length of a planet's year — that is, the length of time it takes to make one revolution around the Sun — have to do with its distance from the Sun? To find out, create different ball/string combinations to represent the orbits of the planets in the Solar System.

Establish a scale to use. Astronomers call the mean distance (average distance) between the Earth and the Sun one astronomical unit (A.U.). Thus, one A.U. is the same distance as 149.6 million kilometers. Astronomers use A.U.s to make it easier to talk about very large distances. For example, the mean distance between Pluto and the Sun is 5,900 million kilometers or 39.44 A.U., which means that the distance between Pluto and the Sun is more than 39 times the distance between the Earth and the Sun.

Mean distance from the Sun (in millions of kilometers)

Mercury	*57.9*	*Mars*	*227.9*	*Uranus*	*2869.6*
Venus	*108.2*	*Jupiter*	*778.3*	*Neptune*	*4496.7*
Earth	*149.6*	*Saturn*	*1427.0*	*Pluto*	*5900.0*

➤

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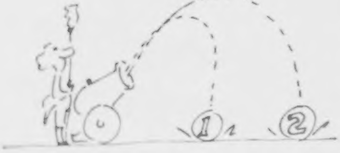
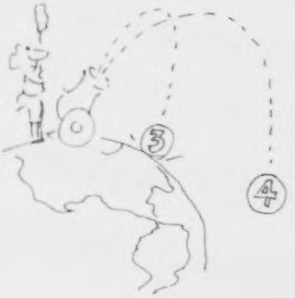
- ★ ***Why does the Earth stay in orbit around the Sun?***
- ★ ***What keeps the Moon going around the Earth?***
- ★ ***What makes up and down on Earth?***





For thousands of years people thought that objects fell to Earth because they were trying to "return to their natural place." The British scientist Sir Isaac Newton thought differently. He called this phenomenon gravity and described it as an attractive force between any two objects.

All objects — even you, even a feather — have a gravitational force that attracts other objects. The strength of the force is related to the object's mass, which is the amount of material the object contains. On Earth, the mass of the Earth itself is so great that its gravitational force completely overpowers the force of any object on Earth.

So how does gravity keep satellites orbiting the Earth? An orbit is the path in space of one object, like a satellite, circling around another object, like Earth. Why don't these objects fall? Actually, they do. But because the Earth is curved and because the satellites are moving, they stay in orbit.

Newton figured this out 300 years ago. He imagined placing a cannon on top of a very high mountain. If he fired the cannon, the cannonball would eventually fall to the ground. If he increased the firepower, the cannonball would fly out farther before it fell, but it would still fall to the ground.

With enough firepower, however, the cannonball would fly far enough away from the Earth to take advantage of the Earth's curved surface. Gravity would still cause it to fall, but at the same time the Earth's surface would "curve away" from the ball. So the ball would never hit the ground. The lateral velocity causes the ball to stay in motion; the "free fall" that the orbiting ball experiences is the cause of weightlessness.

Like the cannonball, satellites fall, too, but they also move forward at a speed that is fast enough to counter gravity. If, for example, gravity pulls the satellite toward Earth at one foot per second, the satellite moves forward fast enough so that the curved Earth "drops" away from it at the rate of one foot per second. In this way, the satellite stays in the same orbit.

Gravity helps to keep objects in orbit by acting as a centripetal force. This force makes objects go in a circular path. If gravity did not exist, these objects would keep moving out and eventually fly off into space.

The Moon is a satellite circling the Earth, and the Earth is a satellite circling the Sun. The Earth's gravity also keeps the Moon in orbit, and the Sun's gravity keeps the planets orbiting around it.

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MORNING STAR AND EVENING STAR

ACTIVITY C-6

GRADE LEVEL: 5-7+

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What's This Activity About?

Once students learn how planets appear to move in the sky over time, they can simulate the apparent motions of Venus in particular. With this activity, they will begin to appreciate why Venus is sometimes seen in the morning before sunrise, sometimes in the evening around sunset, and sometimes is never visible at all.

What Will Students Do?

Students stand in a circle around a single bright light—the Sun—in a dark room, and turn to simulate the passage of time, creating sunrise and sunset. Using a separate ball to represent Venus, the students match the time of day when Venus is visible to them with its position around the Sun.

Tips and Suggestions

- This is an ideal complement to C-4, "Observing a Planet."
- Extend this exercise with a ball representing an outer planet, so that students can see why Mars, Jupiter, and Saturn are visible throughout a night.
- For students in later grades, point out how the "phases" of Venus are also noticeable, as the observed illumination on the Venus ball varies from crescent to almost full. This observation can be tied to Galileo's telescopic view of Venus' different phases and sizes as proof that the planet orbited the Sun, not Earth.

What Will Students Learn?

Concepts
- Planetary motion
- Rotation (spinning about an internal axis to create daily motion)
- Revolution (rotating about an external axis to create annual motion)

Inquiry Skills
- Observing
- Visualizing
- Reasoning

Big Ideas
- Gravity

Morning Star and Evening Star

This activity will help your students to see why Venus appears to us sometimes as the morning "star" and sometimes as the evening "star."

Materials

- ☐ A white light with no shade or reflector. This will represent the Sun.
- ☐ A small white ball to represent Venus. Mount the ball on a stick or pencil.
- ☐ A way to make the Venus stick stand up. It could be stuck into a lump of clay, or taped to the edge of the table.

Preparation

Set up the white light on a table in the front of the class. Make sure there is room for you to move the "Venus" ball in a small orbit (less than one meter radius) around the "Sun."

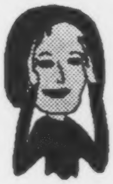
In Class

Turn on the white light and turn off the room lights.

Let's pretend that this bright white light is the Sun, the small white ball is the planet Venus, and your head is the Earth.

Since your head is the Earth, you can imagine people living on "Mt. Nose." What time of day is it on Mt. Nose when you look directly toward the Sun? *(Noon.)* ***What time of day is it when you are facing directly away from the Sun?*** *(Midnight.)*

Put your hands up to form blinders on the sides of your eyes. *(Demonstrate, as shown in the picture).*



Your hands form an eastern horizon and a western horizon. ***Now, turn around to face directly away from the Sun, and then start turning slowly to your left.*** This is the way the Earth turns. You should see the "Sun" during your day. It is night when the Sun "sets" behind your (western) horizon hand and you are facing away from the Sun. When the Sun "rises" from your other (eastern) horizon hand it's morning. ***Behind which hand does your Sun "set," the left hand or the right?*** *(Right.)*

For younger groups, stop and make sure students recall which hand is their right by asking them all to raise their right hands. Help any students who have trouble recalling.

On which horizon does the Sun set, the West or the East? *(West.)* ***Which of your horizon hands represents your western horizon, your left hand or your right hand?*** *(Right hand.)* ***Turn a couple more times slowly so you see the Sun rise and set a couple more times, and then stop at your "noon" position facing the Sun and rest your "horizons." You may put your hands down.***

Hold the white Venus ball about 1/2 meter to the right of the Sun (as seen by your students).

Now we will add Venus to our model. This white ball is Venus. As you turn, you will see Venus and the Sun. When the real Sun is above the horizon, it is so bright that it is very difficult for you to see the real Venus. So in our model, imagine you can see Venus only when the Sun is below the horizon (behind your hand or behind your head). Venus will be visible to you just before sunrise, just after sunset, or it won't be visible to you at all. ***Now, put your horizons back on and start turning slowly to find out if you can see Venus just before your sunrise, or just after your sunset.***

Let the students turn a few times.

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Raise your hand if you saw Venus just before sunrise. (Most of the students will raise their hands.) If you saw Venus just before sunrise, would you call it the "morning star" or the "evening star?" *(Morning star.)* ***Turn around a couple of more times to make sure you can see the "morning star" just before "sunrise."*** *(Help any students who need help.)*

Now stop turning and rest your "horizons." Venus orbits around the Sun and so can appear to be on either side of the Sun.

Make Venus orbit the Sun and finally, put Venus on the other side of the Sun, on the left side from your students' perspective.

If you put up your "horizon" hands and let your "Earth" turn again, do you think you will be able to see Venus before sunrise or after sunset? (After sunset.) ***Try it. Raise your hand if you saw Venus just after sunset.*** *(Most of the students will raise their hands.)* ***Was Venus a morning star or evening star for you?*** *(Evening star.)* ***Turn around a couple more times to make sure you can see the "Evening Star" just after "sunset."***

Help any students who need help.

Do you think that there is any time when you cannot see Venus at all? *(Yes.)* ***When would you not be able to see Venus?*** *(When Venus is either behind the Sun and blocked or in front of the Sun and is drowned out by the sun's brightness.)*

Walk around the Sun with Venus to show its orbit. While you are orbiting...

Raise your hand if Venus is not visible to you because it is behind the Sun.

Go around for at least two orbits.

Now raise your hand when Venus would not be visible to you because it is in front of the Sun, and the sun's brightness would hide it. (Remember, the real Sun is much brighter than this light!)

Go around another two orbits or so.

What you have just modeled is the modern explanation for why Venus is sometimes the "evening star," sometimes the "morning star," and sometimes not visible at all.

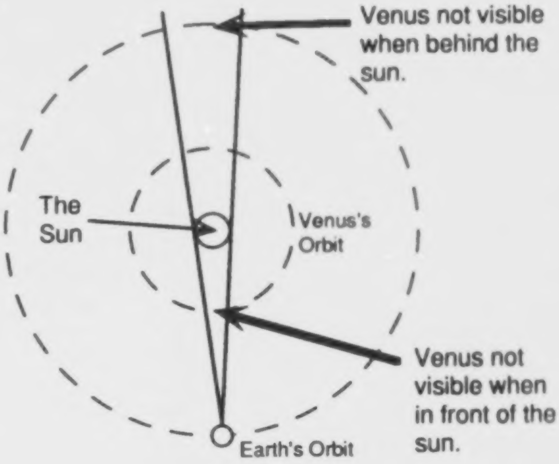
Optional:

Venus's cycle is as follows:

1. Venus appears as a morning star for about 263 days.
2. Venus is not visible when it goes behind the Sun for about 50 days.
3. Venus appears as the evening star for about 263 days.
4. Venus is not visible when it goes in front of the Sun for about 8 days.
5. The entire cycle of Venus is 584 days long.

Why do you think that Venus's time of non-visibility is longer when it goes behind the Sun than when it goes in front of the Sun?

A diagram helps to answer this question:


Venus not visible when behind the sun.
The Sun
Venus's Orbit
Venus not visible when in front of the sun.
Earth's Orbit

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VENUS TOPOGRAPHY BOX

ACTIVITY C-7

GRADE LEVEL: 4-12

Source: Based on ideas developed by Larry Lebofsky of the University of Arizona's Lunar and Planetary Lab, and Elizabeth Roettger of The Adler Planetarium. This version was adapted by Scott Hildreth and the staff of Project ASTRO at the Astronomical Society of the Pacific.

What's This Activity About?

If Venus is perpetually covered with clouds, how do we know what its surface looks like? If we wanted to explore Saturn's moon Titan, covered by its cold methane atmosphere, what techniques could we use? How could we decide where to land a probe safely? This activity illustrates the process of gathering data about a surface we cannot see directly. The activity originated from efforts to explore ocean floors on Earth. It is an accurate representation of a current process scientists use to explore our world, and other worlds.

What Will Students Do?

Students use a model called a "topography box" to understand how scientists can create a map of an unseen surface. The box can be made in advance, or students can make their own in a group, and investigate each other's simulated terrains. After creating a sample surface, students cover the box with a lid, and sample the depth of the surface beneath the lid with a calibrated "probe."

Tips and Suggestions

- You can use a wide variety of materials to create the model. Plaster of Paris or papier maché work well, but some teachers have used paper, rocks, and stiff aluminum foil with success. Modeling clay can be used, but because it is less solid, you will need to tell students to measure the surface gently. Practice creating your own boxes before asking your students to follow the directions.
- The boxes may take time to create, but they can be used by future classes. As students try to find a "flat" area on which to land a space craft, ask them to determine how many sample measurements need to be made to find the best spot. Sampling a few locations is fast, but may miss the smaller surface features. Sampling more locations takes longer, but provides a much more accurate surface map.
- Link this activity to planetary exploration, robot spacecraft communications, and even planetary geology.

What Will Students Learn?

Concepts

Remote sensing
Spacecraft functions
Planetary exploration

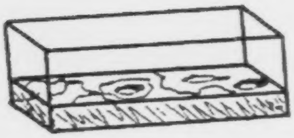
Inquiry Skills

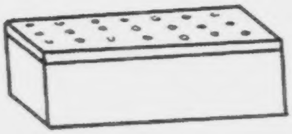
Observing Systematically
Using Instruments
Exploring
Recording
Inferring
Imagining
Communicating

Big Ideas

Models and Simulations
Scale
Structure

Venus Topography Box





Based on ideas developed by Larry Lebofsky of the University of Arizona's Lunar and Planetary Lab and Elizabeth Roettger of The Adler Planetarium. This version adapted by Scott Hildreth and the staff of Project ASTRO at the Astronomical Society of the Pacific.

Aims:

In this activity, students will:

1) *Learn how scientists make an accurate surface model of an "unknown world."*
2) *Learn to make and use a contour map.*
3) *Learn about remote sensing and measuring.*
4) *Develop research and systematic observation skills.*

Key Question

Can you think of a way to "see" through the clouds that always hide the surface of Venus? (Hint: How do airplane pilots landing in San Francisco know where the runway is on a completely foggy day?)

Materials

To create the hidden world: A corrugated cardboard box or shoe box with lid, Plaster of Paris, stucco, Styrofoam, paper mache, or rocks and glue. Alternatively, Pla-Doh, or modeling clay can be used to create mountains or valleys, but these softer materials must be covered by a solid material (like multiple sheets of newspaper or construction paper). An awl, leather punch or other sharp object to make holes.

To map the hidden world: A pencil or stick, two pieces of graph paper, tape, rulers for each student or group.

The Activity

Description

Students use a model called a "topography box" to learn how scientists make maps of unseen surfaces. Students map a mock planetary surface by inserting a simple probe—a pencil or stick—at various points through a box top to touch the surface below. They record the depth to which the probe descends, and use this data to make a contour map for the surface, showing physical features like mountains, plains, and valleys.

Introduction

Venus is an extremely difficult planet to study. It has a very dense and cloudy atmosphere that always hides the planet's surface. With its sulfuric acid clouds and an average temperature of almost 900° F—hotter than the self-cleaning cycle of your oven—we are unlikely to send a team of human explorers there soon! Most of the information we have gained about the surface of Venus has come from radar, which is able to penetrate the clouds and is reflected by the surface. By measuring the times between sent and reflected pulses, scientists can detect hills, valleys, rough and mountainous regions, smooth plains, and even volcanoes. With this data, scientists construct topographic maps of surface features. We call this measuring method "radar altimetry."

Several spacecraft from Earth have visited Venus. The most recent was Magellan, which orbited Venus from 1990-1994. Magellan mapped over 98% of the surface of Venus. Along with the distance, Magellan also measured how much of the radar signal came back from each point on Venus, which can tell us how rough or smooth the surface is.

Magellan's radar images of Venus revealed a surface with plains, impact craters, and volcanoes, but also with intriguing features that have never been seen on any other planet in our solar system. Some areas on the planet are covered with strange, smooth round volcanic mounds a few hundred meters high, known as "pancake domes" because or their appearance. Other areas are covered with a vast network of crisscrossed parallel cracks. Complement this activity with a display of the actual Magellan photos, and encourage students to examine the photos for different terrain.

Making the Model

Use Pla-Doh, modeling clay, stucco, or even Styrofoam to mold an irregular surface (with mountains, valleys, plains, etc.) inside a sturdy box with a cover, like a shoe box. Make one topography box for every 3 or 4 students; you can either make the boxes identical, so that the groups of students can collaborate, or make each different, which can be even more fun. For later grades, have groups of students make the boxes for other groups. (If students do make their own boxes, ask them to keep their designs secret, and to label the box with their names.) Also consider drawing or painting on the surface; after all, radar and other forms of remote sensing do not measure everything. Note that the softer the material inside the box, the more likely poking a stick into the box will destroy it.

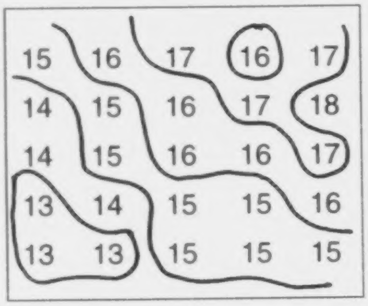
For a more sturdy model that you will be able to use multiple times, create the surface by crumpling newspaper and covering it with aluminum foil. Pour Plaster of Paris or apply paper mache over the foil, and spread the plaster all the way to the box sides to anchor the surface. It's best to have 1-3 "mountains" or one complex feature in a box; try to make the highest and lowest points about 10 cm different in height.

The box and its special interior represents the surface of Venus—the box top represents the Venusian clouds, which we cannot see through. Tape or glue a piece of appropriately-sized graph paper to the box top. The graph paper's grid will serve as the sensing point for the probe. Using a sharpened pencil, awl, or leather punch, punch small holes in the grid every 3 or 4 centimeters in the box top. Numbering the holes will help students track which points they have probed.

Trace the pattern of box-top holes on a second piece of graph paper, and label each point with its appropriate number. This paper will serve as the students' data sheet, where they will record the probe depths at each point.

Contour Maps

Contour maps are a way of showing different heights (or elevations) of a particular area on a flat piece of paper. Contour maps looks like groups of loops and lines (contours), often with numbers (heights) written along the contours or at various places on the map. Each contour traces the ground at a particular height; since high ground rests on lower ground (ignoring caves), the contours never cross. Where the loops and lines are closest together, the terrain changes in height quickly, indicating steep slopes or cliffs. Where the contours are far apart, the terrain is relatively smooth.



Contour maps on Earth are used most often to show mountains and valleys—for hikers, geologists, oceanographers, military commanders, and many other people. Often, these contours are superimposed on a different kind of map to also indicate vegetation, forests and deserts, population, or weather.

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Related Activities

- *Use a rock to explain contours. Dip a smooth rock a little way into a basin of water, and outline the wet spot on the rock with a waterproof marker. Holding it the same way as before, dip it a little deeper and outline a new wet part. Repeat, dipping a little deeper each time. The lines drawn will form contours.*

- *Learn how to read a topographic map. Study a topographic map of your area.*

- *Examine radar images of Venus from the Magellan spacecraft and find out what scientists have learned about Venus. Compare the features on Venus to those on Earth (land and ocean floor), other planets, and moons. Look for mountains, ridges, volcanoes or craters. Also look for features that seem unique.*

- *Understand how the formula speed x time = distance is used to make a radar map. (The radar signal travels at the speed of light, 300,000 kilometers per second. By timing how long the radar signal takes to reflect off the surface and return to the orbiting spacecraft, computers on the orbiter were able to determine the measure the height of the surface, just like measuring the length of the probe.)*

- *Learn how animals such as dolphins or bats use a similar distance finding technique to "map" their surroundings.*

Observations

1. Put the top on the box, and do not allow your students to peek inside. Divide students into groups and explain the model.

2. Tell students that they represent a scientific research team specializing in radar mapping. NASA wants to land a spacecraft on an unseen (cloud-covered) area of Venus. Their job is to decide the best place for the spacecraft to land. Hand out copies of the instructions.

3. Have your students probe the surface by carefully inserting a pencil or stick (representing the radar) through each hole in the box top. The probe will extend into the hole to different depths, depending upon the terrain beneath the hole; students should be warned not to jam the probe into the surface (especially if it was made of clay or Pla-Doh), but instead stop once the probe has reached a firm area. Your students should measure the length of the probe that was inside the box at each point. They can round off the probe length to the nearest centimeter.

The probe lengths will indicate the heights of the surface features at those points. For later grades, ask your students how the length of the probe beneath the box top relates to the surface. Some will make the connection that the shorter the probe descends beneath the box top, the higher the surface must be at that point. Conversely, the deeper the probe descends, the lower the terrain is at that point.

Students should then record the rounded probe length beside the corresponding dot on their graph paper.

4. After students have probed all of the holes, ask them how they can use the information to make a map of the surfaces. (One method would be simply to color code all areas of the same height. This is faster and effective, but not as informative as creating a contour map that links all of the dots of equal height with loops. Show students how to group their measurements into a topographical map.) Note that colored pencils or crayons can help to make the contour maps more striking. Students can shade in the loops with different colors, starting with the highest or lowest areas.

5. Ask students to analyze their maps, and determine what would be the best location for a landing.

6. Discuss the choice of landing sites. What criteria did the students use? Ask the students to consider whether the area could still be covered in small boulders, large enough to endanger a space craft, but too small to be noticed by the probe. Or perhaps, the surface could

have narrow cracks that also might have gone undetected. Ask the students what other features the probes might have missed.

These issues are related to the important concept of *resolution*, the ability to detect detail when measuring. Hold up a coin in your classroom, and ask students to identify it—most will be able to tell the denomination from its size. But now ask if any can read the writing on the coin; only those extremely close to you might be able to see that there is writing, and even they will find it difficult, or impossible, to *resolve* the individual letters. In the Venus Topography Box experiment, resolution is limited by the number of probe holes, and the size of the probe. Fewer holes probed means poorer resolution—students will have a less accurate model of the surface. More holes will mean a better map, but it will take longer to complete the model. The follow-up questions after the activity will investigate resolution.

8. Have each group find the spot on the box that corresponds to the chosen landing site and remove the box top. Compare students maps with the true topography. Ask students to discuss what they mapped accurately, and what areas were mapped less accurately.

9. If different topography boxes were constructed, open them and mix up the maps. Ask students to determine which map corresponds to each box.

Follow-Up Questions

1. How could we make a more detailed map of the surface?
Students might answer: By using more holes, closer together, and also using thinner probes which would detect smaller difference in terrain. Cite an example to illustrate this last point—ask students to consider drawing a picture with a thick piece of chalk compared with a sharp pencil. Which picture will be contain more detail? Compare a pencil with a thin bamboo skewer. Which probe would provide better resolution?

2. Where else could we use this technique for map-making?
Students might answer: Other planets and their moons, ocean floors, remote areas difficult to reach by land. It is interesting to note that this *activity traces its origins to scientists' efforts to map the ocean floor.*

3. What are some reasons pilots, divers, or hikers would use a contour map on Earth?

Instructions to the Mapping and Exploration Team

NASA has launched a Planetary Explorer spacecraft and put it into orbit around Venus. The ship is equipped with a remote sensing instrument (a radar) and a robot Lander.

Your team has been asked by NASA to map a region of the planet's surface and recommend the best place to land the robot. There is some disagreement over the kind of place that would be best, so you will have to explain your decision:

Scientist's suggestion: "Pick the most interesting spot, like a volcano or an imposing mountain."

Engineer's suggestion: "No! We spent years building this robot, so pick a smooth, flat, safe place."

You will need to show your map to the NASA representative, point out the high spots and low spots, identify the gentle slopes and steep slopes (if any), and point out the area you think is best to land the robot.

Directions

Your box has Venus terrain inside. The closed top represents the clouds which prevent you from seeing the surface visually. To learn about the surface, you will have to probe the surface with radar, which can penetrate the clouds.

1. Take data as the spacecraft orbit passes over the region of interest.
Lower the probe into each of the holes, until the end gently touches the surface below.

2. Calibrate the instrument at each point and record the result.
Hold the pencil at the "cloud top" (box top) and pull it out. Measure the length of the pencil from the point that touched the surface to the box top. Write down the measurement next to the matching point on your graph paper, and round to the nearest centimeter. Make sure the radar is aimed correctly (the stick is straight up and down) and that the recording device is working properly (write the numbers in the right places).

3. Produce a contour map.
Start with the smallest probe depths, and draw a closed loop touching all of the points of the same measurement. (If there is only one point with that measurement, draw a small circle around that point only.) Continue with the next larger probe length, and draw another closed loop enclosing each point that is about the same depth measurement. Note that this loop should enclose all of the smaller measurements, too! Don't let your new lines cross any old lines.
For example, draw a loop around all the points that are about 13 cm deep. Then, draw a larger loop around all the points that are about 14 cm, 15, 16, 17, 18, and finally 19 cm.

Keep going until you draw a loop around all the points of the same measurement. Note that in some cases, you will have to make more than one loop between two numbers that differ by more than one.

4. Identify geologic formations.
Where are the high and low places, steep and gentle slopes? Are there any mountains? Valleys? Craters? Hills? Plateaus? Cliffs? Where shall we land the spacecraft?

5. Report your results to your NASA representative.
Be able to point to the spot on the box top where you want to land our spacecraft. When your teacher approves, remove the box top and identify the landing site. Land your robot spacecraft!

6. Evaluate the results.
Did you choose a good site? How well does your map match the actual surface? What information about the surface were you unable to learn using this mapping method?

7. Analyze your experiment
How could you improve your survey of the surface?

MARTIAN CANALS

ACTIVITY C-8

GRADE LEVEL: 4-9+

Source: Reprinted from the Aerospace Education Services Program curriculum guide. Available from the Oklahoma State University Aerospace Professional Development Center, Suite 308-A, Center for International Trade Development, Oklahoma State University, Stillwater, OK 74708; (405) 744-6784. Funding provided by NASA.

What's This Activity About?

One hundred years ago, astronomers and people around the world hotly debated the significance of dimly seen markings observed on the planet Mars. Were those marks actually *canals*, built by some intelligent beings to move water? Were they simply *channels*, created by different terrain and/or atmospheric conditions? Or were they there at all? The answer was significant for our entire human species, and many astronomers spent their careers trying to observe and explain those puzzling markings.

Upon closer observation by the Mariner 9 spacecraft, the "canals" thought to be built by intelligent beings turned out to imaginary. But why had learned scientists considered them to be possible? When we observe apparently random structures from a distance, our eyes and brain often can create patterns. Research has shown that as distance from the image increases, observers imagine straighter features.

This wonderful activity demonstrates to students how brief glimpses of a random pattern can be interpreted as a series of linear features, and we encourage you to try it. The activity has historical significance, but recent reports of "faces on Mars" (see section K) show us that some people still believe apparent markings are actually deliberate creations.

What Will Students Do?

Students observe a picture for two minutes and draw what they see. The sketches are collected and compared based on the distance of the observer from the picture. Observers who are farther from the picture may draw significantly different images, with more straight features, compared with those closer to the picture.

Tips and Suggestions

- This activity can also be used to explore the effect of atmospheric turbulence or weather on observations. Turn on a hair dryer underneath the picture, and compare the images students draw. Or lower the light level in the classroom, and repeat the experiment. These extensions relate to resolution, the ability to discern detail. See "What Makes Good Viewing?" in the *Tools of the Astronomer* activity section.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Resolution of planetary surface features	Observing	Simulations
Observing artificial patterns	Inferring	Structure
	Reasoning	

Classroom Activities

Martian Canals

SUBJECT: Astronomy
TOPIC: Remote Sensing
DESCRIPTION: A possible resolution of the "true" origin of the Martian canals is demonstrated with a pencil and paper activity.

CONTRIBUTED BY: Gregory Vogt, OSU

MATERIALS:

Enlarged version of the figure
Blank drawing paper
Marker pens or dark crayons

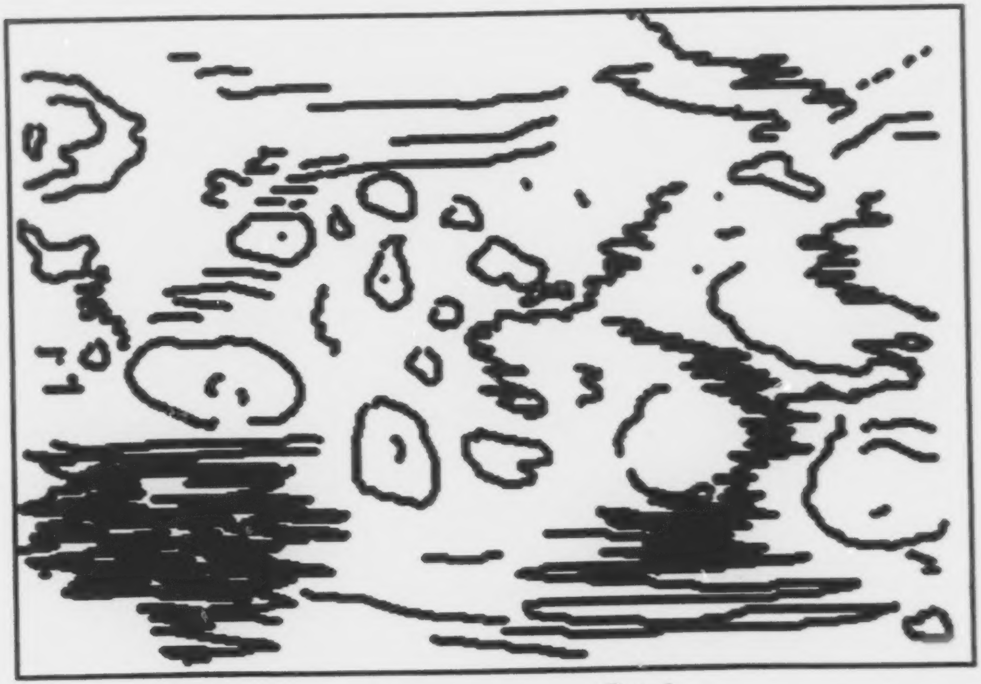
METHOD:

1. Draw an enlarged version (about 21 x 28 cm) of the figure on a piece of white paper.

2. Distribute blank paper and markers or crayons to the class. Hold the figure up in front of a class for two minutes.

3. Instruct the class to quickly copy the figure on their paper.

4. After two minutes, collect the drawings from the students. As they are collected, mark each one with a code indicating how far the student who drew each picture was away from the original.

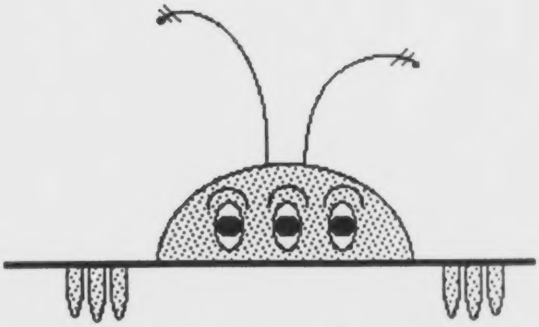


5. Affix each drawing to a bulletin board and arrange them by distance.

6. Compare the drawings to each other. What differences are visible between the close up and far student drawings?

DISCUSSION:

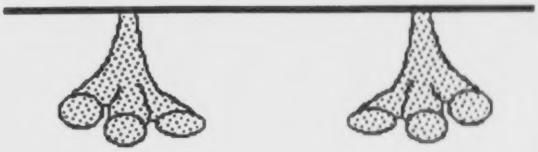
In 1878, Giovanni Virginio Schiaparelli, directory of the Brera Observatory in Milan, Italy, published "Astronomical and Physical Observations on the Axis and Rotation and on the Topography of the Planet Mars." The report was probably the first official mention to the scientific community of his discovery of *canali* crossing the surface of Mars. The word means "channels" but it was promptly mistranslated by news reports as "canals." On Earth, canals were made by humans. Schiaparelli's report triggered a Martian odyssey lasting close to 100 years. The popular press and notable scientists took the discovery to mean that the planet was populated by "intelligent creatures, alike to us in spirit, though not in form." Other scientists believed Schiaparelli was just connecting, in his mind, the shadowy features on the Martian surface into an elaborate network of canals. Eventually, the Italian astronomer believed he had identified 113 canals. The American astronomer Percival Lowell elaborated on the observations and boosted the canal count to 500 and further identified 200 "oases." A scientific debate ensued that was not finally laid to rest until 1972 when Mariner 9 orbited the Martian surface and sent back thousands of pictures, none of which showed any canals.



In 1913, E.W. Maunder, conducted an experiment with 200 English schoolboys in which he hoped to show the Martian canals were just optical illusions. He instructed the schoolboys to copy a figure like the one on this page. Maunder found that the farther away the drawer of the picture was from the original, the less detail and the straighter the lines on the copy became. His experiment provided a strong indication that the Martian canals were merely chance alignments of surface features and colorings on Mars that appeared to be linear.

Incidentally, Mariner 9 did detect hundreds of real channels on Mars but none were large enough to be seen from Earth.

REFERENCES: Vogt, G. L., (1978) "Lessons from the Great 'Canal' Dispute," *The Science Teacher*, v45n7, pp27-29.



PLANET PICKING

ACTIVITY C-9

GRADE LEVEL: 4-9+

Source: Reprinted with permission from *Astro Adventures*, by Dennis Schatz and Doug Cooper, ©1994 by The Pacific Science Center. No reproduction of this activity of any sort is permitted without written permission from Pacific Science Center. Order *Astro Adventures* (including set of 18 slides) from Arches Gift Shop, Pacific Science Center, 200 Second Ave. N., Seattle, WA 98109-4895; (206) 443-2001. Sets of Planet Picking photos also available at above address in poster sized sheets of paper (Planet Picking Poster), ready to be cut out. Book order form provided in the *Resources & Bibliographies* section of this notebook.

What's This Activity About?

In the annual teachers' workshops given by the Astronomical Society of the Pacific, attendees have unanimously reported that Dennis Schatz' "Planet Picking" activity is one of the very best open-ended inquiry and classifying exercises. Start your exploration of astronomy with this, or use a similar approach with other sciences like geology, botany, or biology. "Planet Picking" will stimulate discussion, encourage group interaction and collaboration, and energize your class for further study.

What Will Students Do?

Students classify features visible in a series of photographs or slides based on a classification scheme of their own choice. They examine the images for similarities of structure, composition, color, scale, shape, or other properties, and report their groupings to other groups.

Tips and Suggestions

- The categories students create can all be valid—there are not necessarily right or wrong answers here.
- We encourage you to get the slides or a classroom set of posters for this activity. As an alternative, you can create your own from the descriptions provided, or use the process described with pictures you find from other sources.
- Be prepared to challenge students to create new categories. Some students will resist making new categories once they have created their first classification. Emphasize the importance of thinking in new ways and encourage students to see how many ways they can classify the photos.

What Will Students Learn?

Concepts

Planetary features

Inquiry Skills

Observing
Organizing
Ordering
Reasoning
Communicating

Big Ideas

Scale and Structure
Diversity and Unity
Patterns of Change

PLANET PICKING

Many students find studying the planets in our solar system the most interesting part of astronomy. This activity encourages students to identify the similarities and differences among the planets by examining a number of planetary photographs. This introduction to the planets leaves the students eager to know more about the individual planets.

CONCEPT

Astronomers base inferences about planetary features upon observations of the earth.

OBJECTIVES

Students will:

- compare specific similarities and differences among the planets by examining various features visible in photographs.
- identify types of features found on planets by classifying the photographs into groups, using a classification scheme of their choice.
- infer planetary features based upon earth observations.

MATERIALS

Planet Picking Photos (one set of 18 per four to six students)
magnifiers (one or two per group)
Planet Picking slides
slide projector
slide tray
slide descriptions

PROCEDURE

Advanced Preparation:
Using the Planet Picking slides as a master, copy enough photo sets for the class to work in groups of four to six. Load slides into slide tray in correct position.

1. Distribute the photographs to groups of four to six students. Supply each group with one or two magnifiers to help them closely examine the features in the photographs. Ask each group to classify the photographs into a number of categories based on a scheme of its choiceJupiter.

   Teacher's Note: If students ask how many categories they should have, tell them that it is up to them, based on traits they choose to use for the categories. Some students will also want to know what is shown in certain photographs. Avoid giving answers at this point. Encourage them to discuss possible ideas.

2 7

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2. Facilitate throughout the classroom. As teams complete their groupings, discuss with them their reasoning behind how they grouped the photographs. Encourage them to try different classification schemes. If time allows, encourage students to continue this process for as long as they are examining and discussing the photographs.

3. Once students are done, ask several groups to explain their classification schemes to the rest of the class. Select a variety of schemes for presentation. Students often think that there is only one right classification scheme for this activity, as well as thinking that there is only one way that scientists might classify objects in general. This is an excellent opportunity to discuss how a collection of objects can be classified in many different ways, depending on the traits chosen for making the categories.

4. Use the Planet Picking slides to analyze the 18 planet photographs. Begin by discussing specific features found in the slides of the earth. Discuss the observations of these earth-based photographs, progressing to the earth-from-space photographs.

   Ask:
   - what white features might be (snow, clouds).
   - what blue or blue-green features could be (water, sky, tree-covered mountains).
   - what tan or brown features can be (desert, beach).

   Have students identify these features in the first four photos. Share the slide description information as the students discuss each slide. Use the next five photos to have them identify what they are seeing from space.

   Teacher's Note: The immediate goal is not for students to be able to produce the right answer, but to go through the reasoning process that a scientist would use while examining these photographs. Extensive discussion should be allowed, based on the background knowledge of the students and the information available from looking at the photographs. Information you present about the photographs should occur only after extensive discussion among the students. The goal of the activity is to base planetary inferences upon similar observations made on earth. Due to the nature of other activities in this unit, try not to give away all of the details about each planet.

5. Show slide 10, the Mars slide. Ask students to determine the general terrain on Mars, using the colors observed (red = desert, white = polar caps). Examine the images of the Martian features in the next two slides and compare these to similar earth features (volcano and riverbed).

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6. The craters visible on Mars can then be used as a lead-in discussion of similarities to the Moon and Mercury, shown in the next two photographs (low density atmosphere and resulting lack of erosion allows craters to remain visible for millions of years.)

7. Complete the analysis of the remaining images, being sure to highlight the items given in the following descriptions of the slides.

DESCRIPTIONS OF PLANET PICKING SLIDES

1) Pacific Science Center with the Olympic Mountains in background: Colors of the natural objects give clues to their nature. Snow and clouds are white, the sky is blue, and trees in the distance are blue-green.

2) Sandstone cliffs along the coast of southern Australia: Colors of features provide more clues to nature of the environment. Water is blue and sandy areas are beige.

3) Mt. Shasta in northern California: Slide shows a volcano on earth for comparison to other planets. It also reinforces use of color to determine nature of the environment. Clouds and snow are white. Sky is blue. Trees in the distance are blue-green, while nearby trees are green. Gray outcroppings of rock are also visible on the sides of Mt. Shasta.

4) Blue Mountains near Sydney, Australia, as viewed from an airplane: Information on colors from previous slides can be used to determine the nature of this environment. White area is clouds, blue-green areas are trees, and the beige features are sandstone cliffs.

5) Sinai Peninsula, as viewed from *Gemini 11* spacecraft: Colors provide evidence for nature of the terrain. The beige indicates it is a large desert. The blue is water.

6) Los Angeles and Santa Catalina Island, as viewed by *Apollo 9*: Exploring the nature of the different colors helps determine what part of earth is in the photo. The blue is water and the white over the water must be clouds, since snow could not exist on the water. Most (if not all) of the other white areas are clouds because shadows from the clouds can be seen on the land below. Beige sandy beaches and blue-green forest areas are easily seen. The grayish area in the center of the photograph is often mistaken for a rocky area, but is really the view of urban Los Angeles.

7) Red River in Louisiana, as seen from *Apollo 9*: Human-made artifacts visible in the photo include an airport, a series of buildings, a road and the square pattern of harvesting the land. The Red River is red because of the high iron content in the water.

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8) Hurricane as seen from *Apollo 9*: This storm in the Pacific Ocean is several hundred miles across.

9) Almost full earth as seen from *Apollo 11*: This photo shows the overall cloud patterns and the extensive water areas on earth. The extensive desert areas of North Africa and the Middle East are the bright beige areas in the center of the slide.

10) Mars: Beige color of planet indicates that it is a desert, except for the two white features at opposite ends of the planet. Being white, these could be clouds or snow. They are the two polar caps of the planet. The polar ice is primarily frozen carbon dioxide (dry ice), but also contains some water ice.

11) Dry riverbed on Mars, taken by *Mariner 9*: Similar in structure to the Red River (in slide 7), this photo shows why astronomers believe Mars once had running water, producing this riverbed.

12) Nix Olympus Volcano on Mars, taken by *Mariner 9*: The largest volcanoes in the solar system occur on Mars. They are similar to the large shield volcanoes that make up the Hawaiian Islands.

13) Full Moon: The large crater Tycho can be seen near one edge, while most of the major maria are located in the opposite hemisphere from the crater.

14) Mercury as seen by *Mariner 10*: This composite picture shows the same type of extensive cratering that is seen on the Moon. This indicates that the conditions on the Moon are similar to those on Mercury. The bodies are about the same size and neither have an atmosphere that would produce erosional forces (such as rain or wind) to erase the craters.

15) Venus as seen by *Mariner 10*: This photo was taken in ultraviolet light. It shows many cloud patterns not observed in visible light. The cloud patterns running roughly parallel to the equator are seen on many planets, including Venus, Earth, Jupiter and Saturn.

16) Jupiter as seen by *Voyager 1*: The giant red spot (three earths could fit inside it) shows the same spiral wind pattern seen in the hurricane on Earth in slide 8. Smaller spiral wind patterns are visible at various locations on the planet. This slide also clearly shows Io, one of Jupiter's moons.

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17) Saturn as seen by *Voyager 1*: The cloud patterns parallel to the equator are easily seen, but not as distinct as previous slides of planets showing the same trait. Saturn is not the only ringed planet in the solar system. Both Jupiter and Uranus have rings, but they are much fainter.

18) Pluto: The best photos of Pluto show it as just a pinpoint of light, similar to the distant stars. We know it is a planet because it changes its position relative to the background stars, as shown in these two photos taken 24 hours apart.

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SOLAR SYSTEM BINGO

ACTIVITY C-10

GRADE LEVEL: 4-9

Source: Reprinted by permission from *Solar System Bingo* produced by the Lake Afton Public Observatory, 1845 Fairmount, Witchita, KS 67208. Copyright ©1990 Lake Afton Public Observatory. Cost: $13.50, Additional educational materials are also available. Write for a flyer.

What's This Activity About?

Learning about the solar system involves comparing and contrasting planetary features, but simply listing characteristics and asking students to recall them may not be the best path to mastery and understanding. "Solar System Bingo" is a fun way to help our students to categorize and then analyze the planetary features.

What Will Students Do?

Students use individual bingo cards, listing four planets and four general characteristics, including distance, size, surface, atmosphere, temperature, composition, and special features. As the teacher calls out a planet, and a specific general feature, students examine their card for a match.

Tips and Suggestions

- Create your own cards, or have students create their own. Brainstorm with the students a list of categories, and have them decide what planets belong in each category.
- Creating the cards can be done as a family homework assignment (give students a sample), and even an art project!
- This activity can easily be scaled to any grade level by including more advanced concepts, matched to the material presented in class. For example, high school students could include major moons, asteroids, and even comets as objects, and categories about cratering, surface evolution, density, magnetism, winds, etc.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Planetary Characteristics	Classifying Organizing Comparing	Scale Structure Diversity and Unity

Solar System Bingo

Instructions

Materials

- 36 Bingo Cards
- 20 large feature cards
- one bag markers
- 68 calling cards: 7 Mercury, 8 Venus, 8 Earth, 7 Mars, 8 Jupiter, 8 Saturn, 7 Uranus, 8 Neptune, 7 Pluto

Solar System Bingo was created to introduce students to some of the features found on various planets in our solar system. Each Bingo card has four planets with four features listed under each planet. Each card has a different combination of planets and features.

Hand out one bingo card and at least 10 markers per person. Place the markers on the table near each card. Have the players identify which planets they have on their card. Explain that each card is different.

Begin by drawing a card from the calling cards. Call out the planet name first and then the feature. If the players need help in identifying a feature, the large feature card can be held up to show them what to look for. (We have found that it is easier to find a specific large card if they are kept in alphabetical order.)

If a player has the planet and the feature on his/her card, have them place a marker on it. Make sure that you emphasize the planet. For example, if Jupiter-rings is called, the student must have rings under Jupiter in order to place a marker on his/her card. Rings under Saturn, Uranus, or Neptune don't count.

After calling a planet's feature, set that card aside. (To simplify checking a player's Bingo at the end of the game, place each drawn card in a separate column, according to planet.) Continue drawing cards until a player has "Bingo."

The player has "Bingo" when he/she has four features in a row (up and down, across, or diagonal). After the player has "Bingo," have them read off their planets and features to compare with the features actually called. If all four match, that player wins!!

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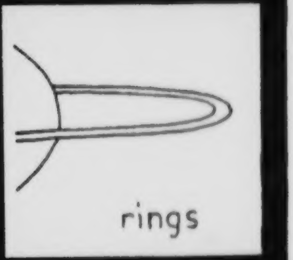
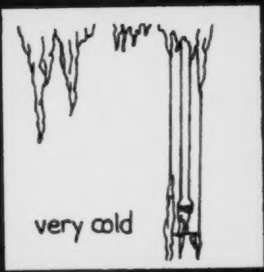
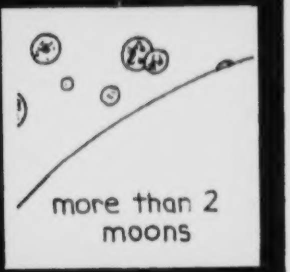
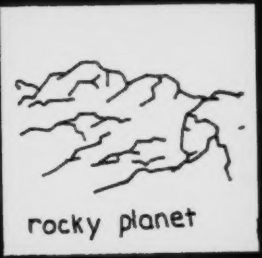
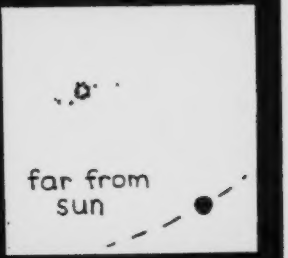
SOLAR SYSTEM BINGO

Neptune	Pluto	Earth	Uranus
very cold	never visited	hurricane	 rings
bigger than Earth	 very cold	volcano	 more than 2 moons
hurricane	smaller than Earth	 rocky planet	 far from sun
gas planet	smallest	craters	thick clouds

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CAN YOU PLANET?

ACTIVITY C-11

GRADE LEVEL: 4-6

Source: Reprinted with permission from *Out of This World.* Copyright ©1994 by the AIMS Education Foundation, 1595 South Chestnut Avenue, Fresno, CA 93702-4706; (209) 255-6396. $14.95 + 10% shipping/handling.

What's This Activity About?

Another method to help students classify planetary characteristics and analyze their observations for trends is to create Venn diagrams and graphs. This Project AIMS activity is a nice example of applying mathematics skills to science. The questions posed for (and by) students about their diagrams can lead them towards the more difficult question of *why* the objects have the features charted.

What Will Students Do?

Students group planetary characteristics on Venn diagrams, and graph numbers of satellites and planetary sizes.

Tips and Suggestions

- The AIMS activity is appropriate for earlier grades, but the organizing principles of Venn diagrams and graphing can easily be extended for more advanced levels. Consider incorporating more objects, such as major moons, asteroids, and comets, or use the activity for comparing stellar characteristics.
- Be careful with the presentation of some of the information here—the planets are not drawn to scale, and the number of moons may change as we continue to explore our solar system.

What Will Students Learn?

Concepts
Planetary characteristics

Inquiry Skills
Graphing
Classifying
Comparing

Big Ideas
Scale and Structure
Diversity and Unity

Can You Planet?

Topic Area
Planets

Introductory Statement
Students will learn about various aspects of the planets and their relationships with one another by using tables of planetary facts, Venn diagrams, and drawings of the planets themselves.

Math
Using attributes
Using whole number operations
Using Venn diagrams and set theory
Using inequalities: larger, smaller
Using tables

Science
Astronomy
  planets

Math/Science Processes
Classifying
Comparing data
Predicting and inferring
Applying and generalizing
Drawing conclusions

Materials
Student activity sheets
Scissors
Pencils
Crayons or markers

Key Question
How can we classify the nine planets?

Background Information

Much has been discovered about our planets as a result of information gathered by Voyagers 1 and 2. Students should be encouraged to look for newspaper and magazine articles which continue to report on new information about our solar system. For example, it was only in September 1991 that some of the newly discovered moons were named.

Management
1. Divide the class into pairs or cooperative learning groups for this activity. Alternate between small group activity and whole group discussions. The last part of the activity may be done in small groups with copies of the planets or as a whole class activity with one copy of the planets.
2. If desired, planet names can be attached to the Venn diagram with paste or tacky adhesive. The tacky adhesive is useful because the titles can be moved if inaccurately placed.

Procedure
1. Discuss with students what they already know about the planets. (total number [nine], appearance, distance from the earth, etc.) Have them tell their sources of information whenever possible.
2. Discuss the *Key Question:* Using Venn diagrams, how can we classify the nine planets? [size, appearance, having moons, etc.]
3. Choose any two table headings for the circles of the Venn diagram. Fill in the appropriate planet names.
4. Use the information from *Planetary Facts.* Color in the proper spaces for the first three attributes. Guide the students to choose three more attributes with which to classify the planets. Have groups compare their results and discuss any differences.
5. Using the two-circle and three-circle Venn diagrams, write the names of the planets in the appropriate places. As a whole class, discuss similarities and differences of the planets from information recorded on the Venn diagrams.
6. Using the *Planetary Facts* and the cutout sun and planets, have students place the planets in the proper order from the sun. Emphasize that order, not distance, is important in this activity.
7. With the whole class, make a list of what has been learned.

Discussion
Using the Venn diagrams:
1. Which planets are larger than the earth?
2. Which planets have moons?
3. Which planets have days longer than 24 hours?
4. Which planet fits all three categories?
5. Which planets have no moons?
6. Which planets are smaller than the earth?
7. What percent of the planets have moons?
8. What percent of the planets are smaller than the earth?
9. Which planets have both moons and rings?

Using the Planetary Facts chart:
1. Which planet has the most moons?
2. What is the total number of moons?
3. What is the average number of moons?
4. Which two planets are the closet in size?

Extensions
1. Enlarge the Venn diagrams so that they will accommodate the cutouts of the planets. Arrange the planets by a variety of attributes such as
   - smallest to largest
   - longest day to shortest day
   - no moons to most moons

   Be sure students label each continuum clearly: which is smallest, etc.

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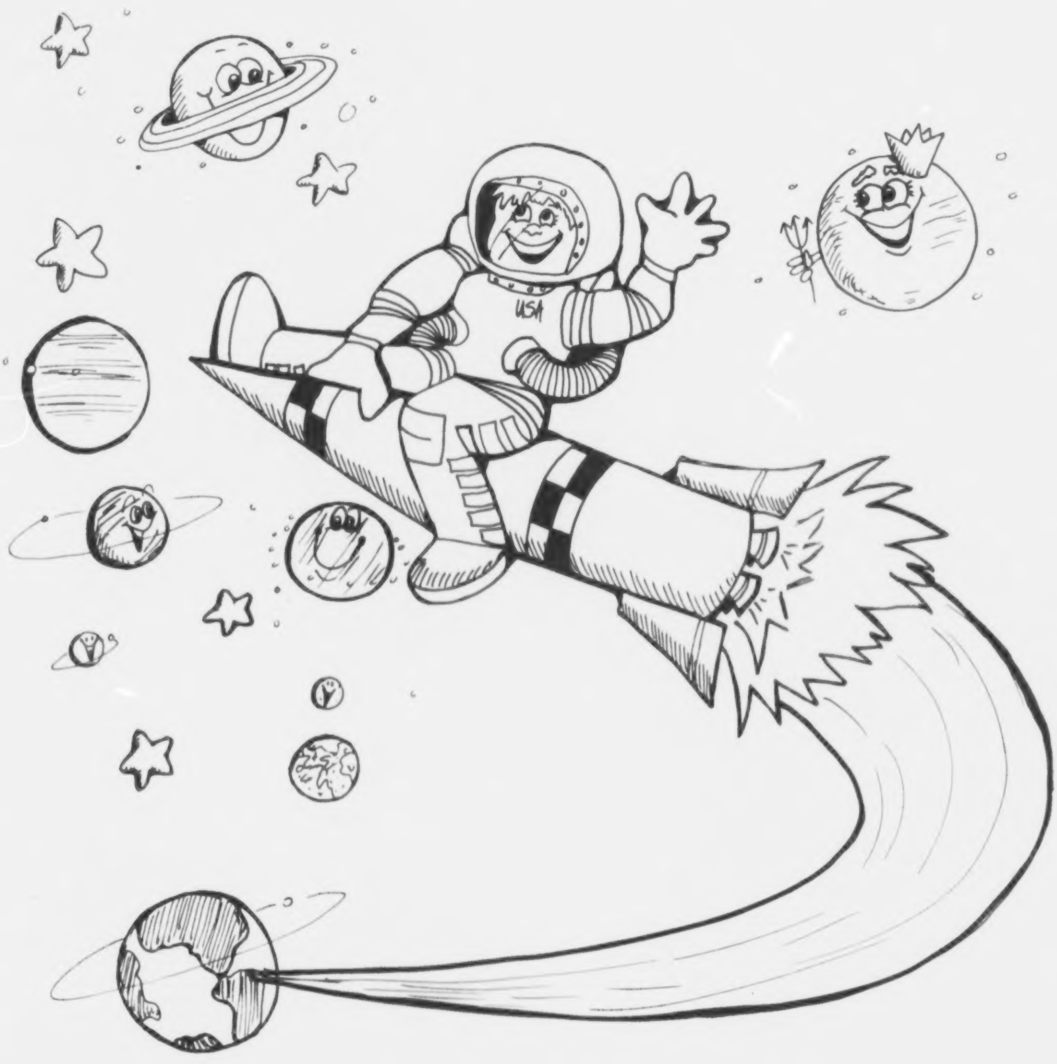
Curriculum Correlations

Language Arts:

Have students do research reports on individual planets. The *National Geographic* is an excellent source.

Art:

Let each group choose a planet to make in papier-mâché by covering a balloon. Have students research the visual characteristics of their planet to represent it as accurately as possible without regard to its size in relation to other planets. Challenge students to create unique ways to show features such as the rings!



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Name:

CAN YOU PLANET?

PLANETARY FACTS

	Approximate Diameter	Approximate Period of Rotation	Moons	Rings ?
Mercury	4,900 km	59 days [176 days]*	0	No
Venus	12,100 km	243 days [117 days]*	0	No
Earth	12,800 km	23 hours, 56 minutes	1	No
Mars	6,800 km	24 hours, 37 minutes	2	No
Jupiter	143,000 km	9 hours, 55 minutes	16	Yes
Saturn	120,600 km	10 hours, 39 minutes	18	Yes
Uranus	51,100 km	17 hours, 14 minutes	15	Yes
Neptune	49,500 km	16 hours, 7 minutes	8	Yes
Pluto	2,300 km	6 days, 9 hours	1	No

* length of day sunrise to sunrise

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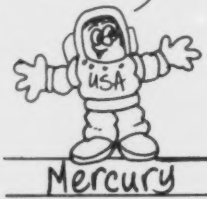
CAN YOU PLANET?

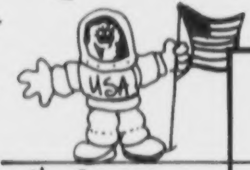
Name

Sort out the planets. Next to each planet's name, color in those spaces that are true. Use this information to place the planets on the Venn Diagram.



Planetary Facts Helping Table

	Larger than Earth	Has Ring(s)	Has Moon(s)
Mercury			
Venus			
Earth			
Mars			
Jupiter			
Saturn			
Uranus			
Neptune			
Pluto			



More Planetary Facts (Venn Again)

Mercury			
Venus			
Earth			
Mars			
Jupiter			
Saturn			
Uranus			
Neptune			
Pluto			

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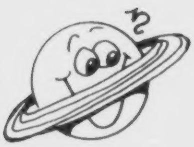
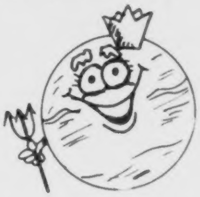
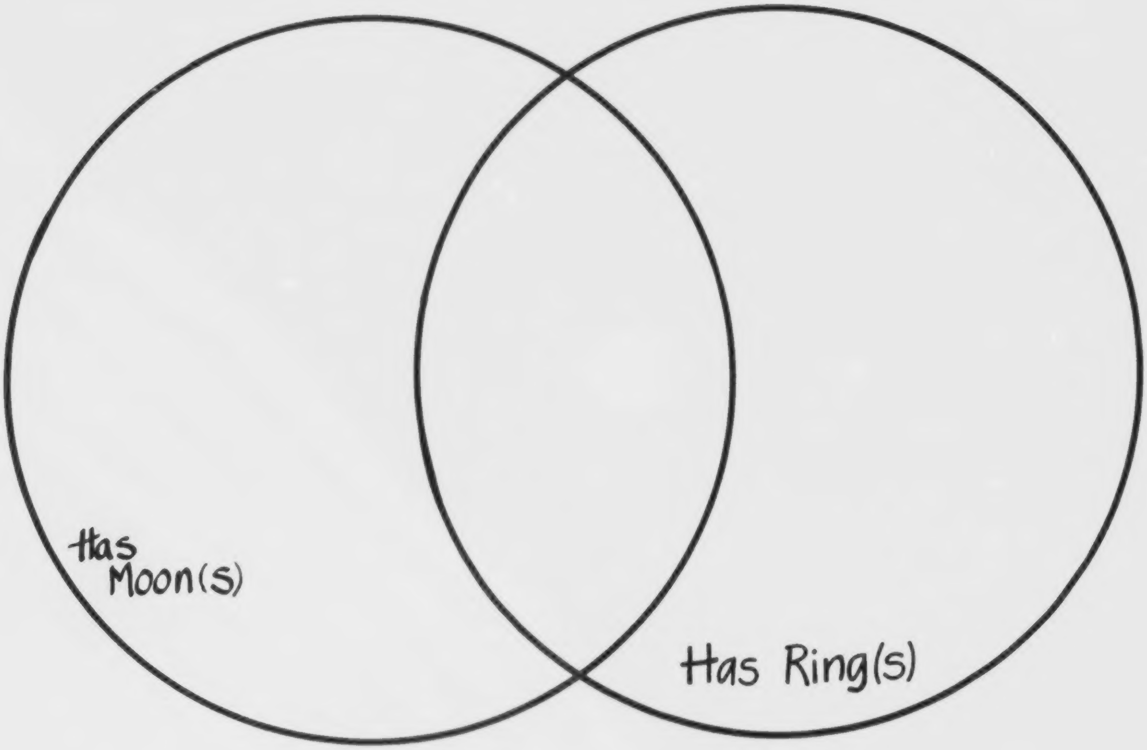
Name: ____________________

CAN YOU PLANET?

Use the information from the chart to place the planets in the correct circle or intersection of circles.







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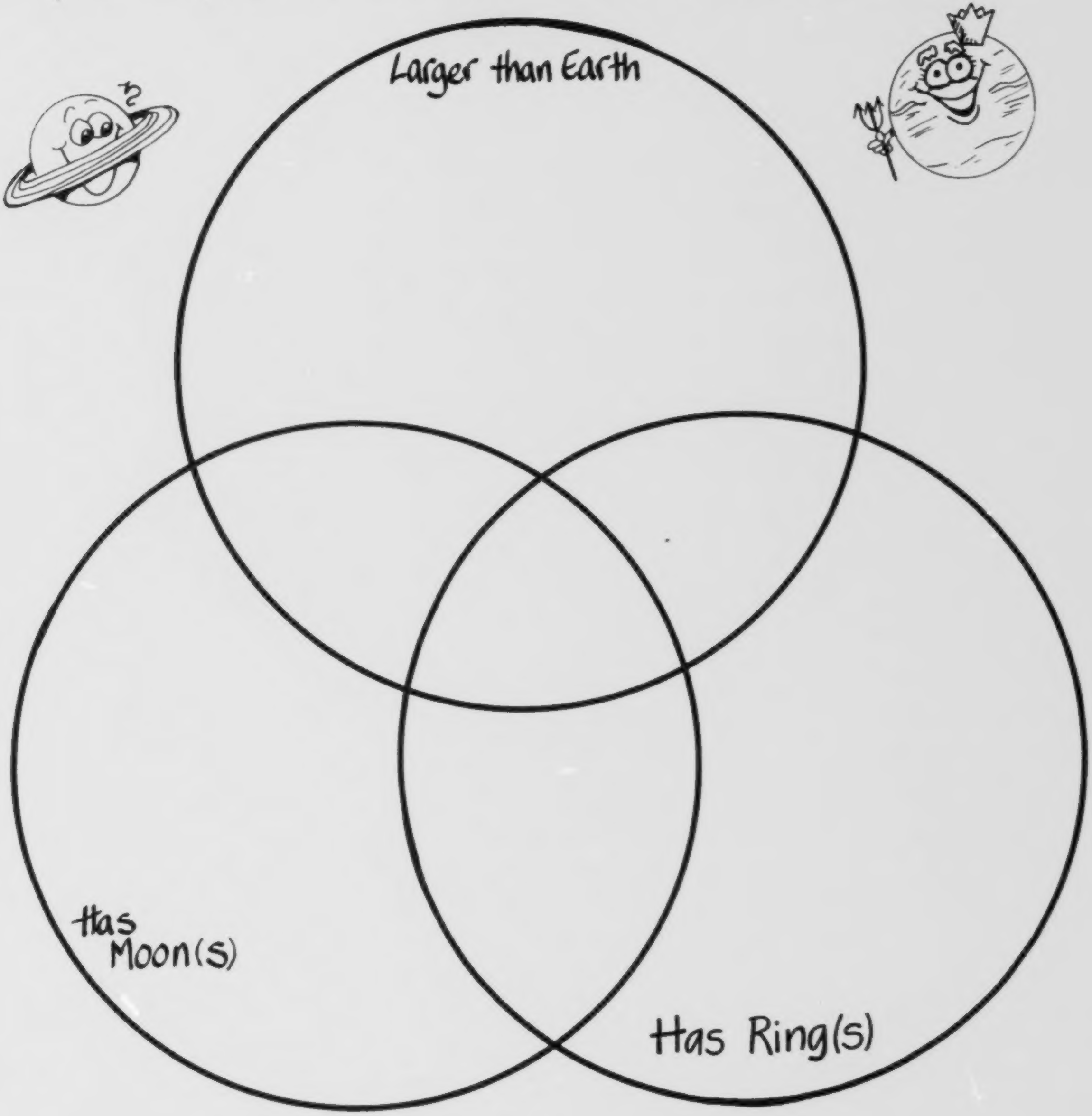
Name: ______________________

CAN YOU PLANET?

Use the information from the chart to place the planets in the correct circle or intersection of circles.


Larger than Earth
Has Moon(s)
Has Ring(s)

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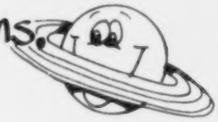
Name: ____________________

CAN YOU PLANET?

Use the Venn Diagram or chart to answer the following questions.



1. Which planets are larger than Earth? ____________________
____

2. Which two planets are closest in size? __________ __________

3. What percent of the planets are smaller than Earth? __________

4. Which planets have moons? ____________________
____

5. Which planet has the most moons? ____________________

6. What is the total number of known moons in our solar system? ____________________

7. What is the average number of moons per planet? __________

8. Which planets fit into all three categories? __________

9. Which planets have days which are longer than 24 hours?
____

Think of two more questions you can ask your classmates. Write them below.

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HOW HIGH CAN YOU JUMP ON ANOTHER PLANET?

ACTIVITY C-12

GRADE LEVEL: 6-9+

Source: Reprinted by permission from *Project Pulsar*, St. Louis Science Center, 5050 Oakland Avenue, St. Louis, MO 63110. Publication is no longer in print.

What's This Activity About?

We have all seen the video of the Apollo astronauts playfully "hopping" around on the Moon's surface. Most students are thrilled with the idea of moving in weightless or low-gravity exploration. After investigating gravity with activities like C-1, "The Earth's Shape and Gravity," students can be asked to extend their understanding to the other planets. This activity introduces the ideas of surface gravity and mass, to help students calculate weight and jumping abilities on different planets.

What Will Students Do?

Students are provided with relative scaling factors for surface gravity on the Sun and other planets. With that information, they measure and compare the heights of their jumps, and their weights.

Tips and Suggestions

- Ask students to consider how other sports, like baseball, soccer or gymnastics might be played on the other planets. For example, they could estimate how far a baseball might travel by using the surface gravity scaling factors. Like jumping, a ball thrown, kicked, or hit will rise higher (and travel farther) on the planets with smaller surface gravities. On some smaller moons of the planets, students might even imagine hitting baseballs into orbit!
- Note that gravitational force depends not only on the mass of the planet, but also on our distance from its center of gravity.
- Students may be surprised that the Sun's surface gravity does not seem very large, considering the Sun is able to "hold onto" all of the planets in the solar system. Remind them that the "surface" of the Sun used in this activity (the layer we see that is called the photosphere) is very far from its center—about 700,000 kilometers.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Gravity	Calculating	Systems and Interactions
Acceleration	Comparing	
	Inferring	

HOW HIGH CAN YOU JUMP?

KEY QUESTION How high can you jump on another planet?

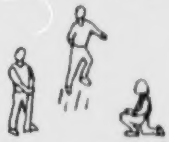
MATERIALS yardsticks, pencils, paper

VOCABULARY gravity, mass, weight

BACKGROUND Gravity

THE MODEL Ask a student to jump as high as he or she can. This is one example of how high one person can jump on one planet (the Earth).

OBSERVATION Give another student a yardstick to hold vertically, touching the floor. And have another student kneel so that he or she can see the yardstick in order to measure the height of the first student's jump. Have the first student repeat the jump, and ask the third (kneeling) student to observe the height of the jump.



SPECULATION Ask your students to speculate about factors that would influence the height of the jump. (gravity, stregth)

EXPERIMENT Have your students record the heights of their jumps, and use the following table to calculate how high they could jump on other planets.

OBJECT	PROCEDURE FOR HEIGHT OF JUMP
Sun	divide by 30
Mercury	multiply by 5 then divide by 2
Venus	multiply by 10 then divide by 9
Mars	multiply by 5 then divide by 2
Jupiter	multiply by 2 then divide by 5
Saturn	multiply by 7 then divide by 8
Uranus	multiply by 11 then divide by 12

continued

From Project Pulsar

HOW HIGH CAN YOU JUMP?

OBJECT	PROCEDURE FOR HEIGHT OF JUMP
Neptune	multiply by 5 then divide by 7
Pluto	multiply by 30
Earth's moon	multiply by 6

The surface gravity of a star, planet, moon, etc. depends upon the object's mass (the amount of stuff present), and the object's radius. The radius is a factor because (1) an object's gravity acts as though its source is at the object's center, and (2) the "strength" of an object's gravity diminishes with distance. For example, suppose that two planets have the same mass, but unequal radii. The planet with the smaller radius will have a stronger surface gravity.

ADDITIONAL How Much Do You Weigh?

From Project Pulsar

Giant Volcano on Mars

RESOURCES FOR EXPLORING THE PLANETS

by Andrew Fraknoi
Astronomical Society of the Pacific
390 Ashton Avenue
San Francisco, CA 94112

NOTE: There is a separate resource list for materials that consider the solar system as a whole in section D of this Notebook. Many of the books listed there have excellent sections on each planet.

Books or articles marked with a • are especially useful for those just beginning their exploration of the solar system.

1. MERCURY

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

Strom, R. *Mercury: The Elusive Planet.* 1987, Smithsonian Institution Press. The definitive non-technical book.

Murray, B. & Burgess, E. *Flight to Mercury.* 1977, Columbia U. Press.

Beatty, J. "Mercury's Cool Surprise" in *Sky & Telescope*, Jan. 1992, p. 35.

Chapman, C. "Mercury's Heart of Iron" in *Astronomy*, Nov. 1988, p. 22.

Cordell, B. "Mercury: The World Closest to the Sun" in *Mercury* Magazine (no relation), Sep/Oct. 1984, p. 136.

Kunzig, R. "Iron Planet" in *Discover*, Feb. 1989, p. 66.

Strom, R. "Mercury: The Forgotten Planet" in *Sky & Telescope*, Sep. 1990, p. 256.

Weaver, K. "Mariner Unveils Mercury and Venus" in *National Geographic*, June 1975.

SELECTED READINGS FOR STUDENTS

Grades 4-6

Asimov, I. *Mercury: The Quick Planet.* 1989, Gareth Stevens.

Barnes-Svarney, P. *Traveler's Guide to the Solar System.* 1993, Sterling Publishing. Good introduction to each planet.

Grades 7-9

Vogt, G. *Mars and the Inner Planets.* 1982, Franklin Watts.

SELECTED AUDIOVISUAL MATERIALS

Mercury: Exploration of a Planet (1976 NASA video, available from Finley-Holiday Films on a tape entitled *Mars & Mercury*)

A map of Mercury is available from Sky Publishing

See the slide sets entitled *The Planetary System* and *Worlds in Comparison*, listed in the bibliography entitled "The Solar System in General. "

2. VENUS

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

Cooper, H. *The Evening Star: Venus Observed.* 1993, Farrar, Straus & Giroux. New book on Venus exploration, including lots of history and the Magellan spacecraft results.

Burgess, E. *Venus: An Errant Twin*. 1985, Columbia U. Press. A summary of what had been learned before Magellan, by a science writer.

Stofan, E. "The New Face of Venus" in *Sky & Telescope*, Aug. 1993, p. 22. An up-to-date summary of what we now know. The same issue includes 3-D views of the planet — with glasses — and a nice article on how the Magellan spacecraft obtains its information.

Burnham, R. "What Makes Venus Go" in *Astronomy*, Jan. 1993, p. 40. An album of Magellan images and information; "Venus: Planet of Fire" in *Astronomy*, Sep. 1991, p. 32. Nice review of first Magellan results.

Naeye, R. "Venus Exposed" in *Discover*, Dec. 1993, p. 76. Nice feature on how the data from Magellan are processed into images.

Saunders, S. "The Exploration of Venus: A Magellan Progress Report" in *Mercury*, Sep/Oct. 1991, p. 130. Steve Saunders was the Project Scientist for the Magellan mission.

Saunders, S. "Venus: A Hellish Place Next Door" in *Astronomy*, Mar. 1990, p. 18. Very nice review of what we knew about Venus before Magellan.

SELECTED READINGS FOR STUDENTS

Grades 4-6

Asimov, I. *Venus: A Shrouded Mystery*. 1990, Gareth Stevens.

Fradin, D. *Venus*. 1989, Children's Press.

Ardley, N. *The Inner Planets*. 1988, Schoolhouse Press.

Opalko, J. "Magellan Discovers a Whole New World" in *Odyssey*, 1992, issue 4, p. 4.

Walz-Chojnacki, G. "Venus: The Original Greenhouse Planet" in *Odyssey*, 1990, issue 7, p. 10. Part of a longer article explaining the greenhouse effect for Earth.

Grades 7-9

Vogt, G. *Mars and the Inner Planets*. 1982, Franklin Watts.

Many of the articles on Venus in *Astronomy* magazine, listed in the first section are fine for students at this level.

SELECTED AUDIOVISUAL MATERIALS

Flying By the Planets (1991 video, Astronomical Society of the Pacific) Includes several computer generated fly-over's of Venus' terrain, as revealed by the Magellan spacecraft radar instrument.

Heaven and Hell (episode of Carl Sagan's 1980 television series *Cosmos*, Turner Home Video; distributed by the Astronomical Society of the Pacific, among others) Eloquent comparison of Venus to Earth

Magellan Highlights of Venus (set of 40 slides with cassette of narration from Finley Holiday Films)

Magellan Highlights of Venus (electronic picture book software for the Mac, from the Astronomical Society of the Pacific) Images and hypercard text from the Magellan mission.

Magellan Reveals Venus (1992 slide set, Planetary Society) 40 images, some in 3-D, brief captions, and 3-D glasses.

On Robot Wings: A Flight Through the Solar System. (1992 video, Finley Holiday Films/Planetary Society) Compilation of a number of NASA videos flying over bodies in the solar system, including Venus.

Venus Explorer (CD-ROM software from Virtual Reality Labs) Lets you zoom around a Venus map generated from Magellan data; a wonderful tool for older students.

Venus Unveiled: The Magellan Images (1991 slide set, Astronomical Society of the Pacific) Assembled with the help of Magellan scientists, this series of 20 slides and detailed booklet gives some of the best images and early results from the Magellan mission.

3. EARTH

NOTE: There is a huge literature of readings about the Earth; the ones below consider our Earth as a planet and take a global and astronomical perspective.

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

- Cattermole, P. & Moore, P. *The Story of the Earth*. 1985, Cambridge U. Press. An introduction by a geologist and a science writer/amateur astronomers.

Chapman, C. & Morrison, D. *Cosmic Catastrophes*. 1989, Plenum. How impacts from space have shaped the Earth's surface and life-forms. (A key section was excerpted in *Mercury* magazine, Nov/Dec. 1989 and Jan/Feb. 1990.)

Erickson, J. *Exploring Earth from Space*. 1989, Tab Books. Clear introduction by a geologist.

- Hartmann, W. & Miller, R. *The History of the Earth*. 1993, Workman. Lavishly illustrated and very well-done chronicle of the planet's evolution.

Sagan, C. *Pale Blue Dot*. 1994, Random House. Magnificent new volume by our country's best-known astronomer focuses on the Earth in a cosmic context; has a great section on how you could determine from space that the Earth has life on it.

Savage, C. *Aurora: Mysterious Northern Lights*. 1994, Sierra Club Books.

Sheffield, C. *Man on Earth*. 1983, Macmillan. Excellent collection of images of our planet from space.

Strain, P. & Engle, F. *Looking at the Earth*. 1992, Turner Publishing. Album of remarkable space images of our planet.

Weiner, J. *Planet Earth*. 1986, Bantam. Nice companion volume to the PBS television series, full of good anecdotes and ideas.

Allegre, C. & Schneider, S. "The Evolution of the Earth" in *Scientific American*, Oct. 1994, p. 66. Part of a special issue on cosmic evolution.

Hartmann, W. "Piecing Together Earth's Early History" in *Astronomy*, June 1989, p. 24.

Chyba, C. "The Cosmic Origins of Life on Earth" in *Astronomy*, Nov. 1992, p. 28.

Broadhurst, L. "Earth's Atmosphere: Terrestrial or Extaterrestrial" in *Astronomy*, Jan. 1992, p. 38.

Evans, D. , et al. "Earth from the Sky" in *Scientific American*, Dec. 1994, p. 70. On interpreting Shuttle radar images of our planet.

Heppenheimer, T. "Journey to the Center of the Earth" in *Discover*, Nov. 1987, p. 86.

Cordell, B. "Mars, Earth, and Ice" in *Sky & Telescope*, July 1986, p. 17.

Gillett, S. "The Rise and Fall of the [Earth's] Early Reducing Atmosphere" in *Astronomy*, July 1985, p. 66.

Lanzerotti, L. & Uberoi, C. "Earth's Magnetic Environment" in *Sky & Telescope*, Oct. 1988, p. 360.

Wong, C. "Watching Earth Move From Space" in *Sky & Telescope*, Mar. 1978, p. 198.

Hurley, P. "The Confirmation of Continental Drift" in *Scientific American*, Apr. 1968.

Many of the books listed in the bibliography for the solar system in general have a chapter on the Earth as a planet. Also, the September 1983 and 1989 issues of Scientific American magazine were devoted to the Earth.

SELECTED READINGS FOR STUDENTS

Grades 4-6

Asimov, I. *Earth: Our Home Base*. 1989, Gareth Stevens.

Lye, K. *Our Planet Earth.* 1980, Lerner.

Bramwell, M. *Planet Earth.* 1987, Franklin Watts.

O'Meara, S. "Volcano" in *Odyssey*, 1993, issue 1, p. 4. On our planet's volcanoes.

Williams, J. "An Ocean of Air" in *Odyssey*, 1993, issue 3, p. 4. On our atmosphere and climate.

Hogan, H. "Mission to Planet Earth" in *Odyssey*, 1992, issue 3, p. 14. On NASA's plans for instruments to observe the Earth.

For grades 7 and up, most earth science textbooks cover the Earth as a planet and its surface characteristics.

SELECTED AUDIOVISUAL MATERIALS

The Aurora Explained (30-min video distributed by Sky Publishing) Wonderful color footage of the northern lights.

Blue Planet (1990 video, Holiday Films/Astronomical Society of the Pacific or the Planetary Society) Reduced from the original IMAX format, this is a visually stunning view of the Earth from space.

The Earth from Space (1990 slide set, Armagh Planetarium/Astronomical Society of the Pacific) 25 images taken from orbit.

Endeavor Views the Earth (Mac software from the Astronomical Society of the Pacific or Sky Publishing) 5 disks with Earth scenes, plus the World Factbook.

Our Planet Earth (23-min video from Bullfrog Films) Astronauts and cosmonauts show and discuss the Earth as seen from space.

Planet Earth (1986 video series, Annenberg-CPB Project/Astronomical Society of the Pacific) Emmy-award winning television series examining the Earth as a planet.

Shuttle Views the Earth (3 slide sets from the Lunar and Planetary Institute) Shows the Earth's oceans, clouds, and geology, as photographed by the astronauts.

Terrestrial Impact Craters (1992 slide set, Lunar and Planetary Institute or the Astronomical Society of the Pacific) 26 slides showing places where cosmic impacts are believed to have happened.

The Third Planet (1987 video, Ambrose Video/available from the Astronomical Society of the Pacific) Part of The Miracle Planet TV series, this episode looks at the origin and evolution of the Earth.

A computer program called *SimEarth* (available from software vendors or the Planetary Society catalog) allows you to simulate the evolution of our planet over time, and with a variety of conditions.

4. MARS

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

- Wilford, J. *Mars Beckons.* 1990, Knopf. The science editor of the New York Times summarizes the past and possible future exploration of the red planet.

Washburn, M. *Mars At Last.* 1977, Putnam's. A science writer's vivid summary of the Viking mission and what it taught us.

Cooper, H. *The Search for Life on Mars.* 1980, Holt Rinehart & Winston. Review of the Viking mission, with a long profile of Carl Sagan.

- Sagan, C. *Pale Blue Dot.* 1994, Random House. Has several excellent sections on the past and possible future exploration of Mars. See also Sagan's 1980 book *Cosmos* for a good chapter on Mars.

Sheehan, W. *Planets and Perception.* 1988, U. of Arizona Press. A fascinating book on the tricks the human eye and imagination can play as we observe the planet, with a good focus on the controversy about "canals" on Mars.

Carroll, M. "The Changing Face of Mars" in *Astronomy*, Mar. 1987, p. 6.

Beatty, J. "The Amazing Olympus Mons" in *Sky*

& Telescope, Nov. 1982, p. 420. On the giant volcano.

Benningfield, D. "The Odd Little Moons of Mars" in *Astronomy*, Dec. 1993, p. 48.

- Gore, R. "Sifting for Life in the Sands of Mars" in *National Geographic*, Jan. 1977. On the Viking mission, with superb images.

Carr, M. "The Surface of Mars: A Post-Viking View" in *Mercury*, Jan/Feb. 1983, p. 2. By one of the mission science leaders.

- Hartmann, W. "What's New on Mars" in *Sky & Telescope*, May 1989, p. 471.

McKay, C. "Did Mars Once Have Oceans?" in *Astronomy*, Sep. 1993, p. 27.

Edgett, K., et al. "The Sands of Mars" in *Astronomy*, June 1993, p. 26. Very nice images of the Martian deserts and the effects of the strong Martian winds.

Albin, E. "Observing the New Mars" in *Astronomy*, Nov. 1992, p. 74. Instructions for observers with telescopes.

SELECTED READINGS FOR STUDENTS

Grades 4-6

Asimov, I. & Reddy, F. *The Red Planet: Mars.* 1994, Gareth Stevens.

Berger, M. *Discovering Mars.* 1992, Scholastic Press.

Fradin, D. *Mars.* 1989, Children's Press.

Ardley, N. *The Inner Planets.* 1988, Schoolhouse Press.

Williamson, R. "Reaching Mars: A 21st Century Challenge" in *Odyssey*, 1992, issue 7, p. 4.

Wills, S. "Build Your Own Planet" in *Odyssey*, 1990, issue 8, p. 12. On terraforming Mars.

Algozin, M. "Dress Rehearsal for Mars" in *Odyssey*, 1991, issue 9, p. 12. On exploring Antarctica to prepare for Mars.

Grades 7-9

Davis, D. & Cattermole, P. *Mars.* 1989, Facts on File.

Vogt, G. *Viking and the Mars Landing.* 1991, Milbrook Press.

Vogt, G. *Mars and the Inner Planets.* 1982, Franklin Watts.

Taylor, G. *Volcanoes in the Solar System.* 1983, Dodd Mead.

For students who have heard about the so-called "Face on Mars" (which is nothing more than a sand-dune, but happens to resemble a human face under certain lighting conditions) a nice activity about other faces in the solar system can be found in the Nov. 1991 issue of *Odyssey* magazine. See also Golden, F. "Facing Up to Mars" in *Discover*, Apr. 1985, p. 92.

AUDIOVISUAL MATERIALS

Blues for a Red Planet (1980 segment of Carl Sagan's *Cosmos* TV series, from Turner Home Video or organizations like the Astronomical Society of the Pacific) This episode is one of the most eloquent evocations of Mars ever filmed.

Mars and Mercury (1979 video, Finley-Holiday Films) Includes the fine 1979 NASA video Planet Mars, focusing on the work of the Viking mission.

Mars Explorer (CD-ROM fromVirtual Reality Labs) Allows you to "fly around" Mars by moving through a detailed map made from Viking images. See also the Vista Pro software from the same company, which allows you to explore scenes on Mars and Earth.

Mars: The Movie (1989 video) This is a brief but delightful computer-generated "fly-over" of Mars, as the planet was revealed by the Viking spacecraft. It is available on the video compilations *Flying By the Planets* (Astronomical Society of the Pacific) and *On Robot Wings* (Holiday Films/the Planetary Society).

New Images of Mars (1985 slide set, the Planetary Society) Computer techniques were used to clean and enhance the color Viking images of the Martian surface in this 20 slide set.

Viking Lands on Mars (1980 slide set, Finley-Holiday Films) 40 slides and a sound cassette.

For more detailed views of the red planets, with an emphasis on geology, there are two slide sets called *Volcanoes on Mars* and *The Winds of Mars: Aeolian Activity and Landforms,* available from the Lunar and Planetary Institute , 713-486-2172.

A wonderful poster, full of excellent information and a map of Mars, called *An Explorer's Guide to Mars,* is available from the Planetary Society. A smaller poster of the two hemispheres of Mars, called Two Faces of Mars, has been put together by Hansen Planetarium and is distributed by both the Astronomical Society of the Pacific and the Planetary Society. A Mars globe is available from Sky Publishing.

5. JUPITER

NOTE: Jupiter has four giant moons, first discovered by Galileo and thus often called the Galilean satellites. Many of the books and articles consider the five worlds together, but we also list a few separate readings about these moons, called Io, Europa, Ganymede, and Callisto.

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

- Morrison, D. & Samz, J. *Voyage to Jupiter.* 1980, NASA Special Publication SP-439, available from the U. S. Government Printing Office. The definitive non-technical book on Jupiter after the Voyager missions, by an astronomer.

- Washburn, M. *Distant Encounters: The Exploration of Jupiter and Saturn.* 1983, Harcourt, Brace, Jovanovich. A fine guide to the Voyager encounters and results by a journalist.

Burgess, E. *By Jupiter.* 1982, Columbia U. Press.

Rothery, C. *Satellites of the Outer Planets.* 1992, Oxford U. Press. A geologist examines the moons as seen by Voyager.

Beebee, R. "Queen of the Giant Storms" in *Sky & Telescope*, Oct. 1990, p. 359. Good discussion of Jupiter's red spot.

Burnham, R. "Jupiter's Smash Hit" in *Astronomy*, Nov. 1994, p. 34. A report on the impact of Comet Shoemaker-Levy 9.

- Gore, R. "Voyager Views Jupiter" in *National Geographic*, Jan. 1980.

Kaufmann, W. "Jupiter: Lord of the Planets" in *Mercury*, Nov/Dec. 1984, p. 169.

Elliott, J. & Kerr, R. "How Jupiter's Ring Was Discovered" in *Mercury*, Nov/Dec. 1985, p. 162.

- Morrison, D. "Four New Worlds" in *Astronomy*, Sep. 1980, p. 6. On the Galilean moons.

Talcott, R. "The Violent Volcanoes of Io" in Astronomy, May 1993, p. 41.

Simon, S. "The View from Europa" in *Astronomy*, Nov. 1986, p. 98.

Harris, J. "Return to a New World" in *Astronomy*, Apr. 1990, p. 30. On the Galileo spacecraft mission that will explore Jupiter starting in 1995.

Hartmann, W. "View from Io" in *Astronomy*, May 1981, p. 17. An astronomer/artist envisions what it would be like to stand on Jupiter's volcanic moon.

Murrill, M. "Voyager: The Grandest Tour" in *Mercury*, May/June 1993, p. 67. Clear summary of all the Voyager encounters.

Olivarez, J. "Seeing the Most of Jupiter" in *Astronomy*, Mar. 1992, p. 85. Observing hints for those with small telescopes.

Smith, B. "Voyage of the Century" in *National Geographic*, Aug. 1990, p. 48. A beautiful summary of the entire Voyager mission.

Talcott, R. "The Violent Volcanoes of Io" in *Astronomy*, May 1993, p. 41.

Reports on the Voyager flybys of Jupiter appeared in *Astronomy* and *Sky & Telescope* magazines throughout 1979.

SELECTED READINGS FOR STUDENTS

Grades 4-6

Asimov, I. *Jupiter: The Spotted Giant.* 1989, Gareth Stevens.

David, L. "By Jove, It's a Jupiter Watch: The Galileo Mission" in *Odyssey,* 1993, issue 6, p. 39.

Ride, S. & O'Shaugnessy, T. *Voyager: An Adventure to the Edge of the Solar System.* 1992, Crown. Written by America's first woman in space and a science teacher, for the younger grades.

Harris, A. & Weissman, P. *The Great Voyager Adventure.* 1990, Julian Messner.

Apfel, N. *Voyager to the Planets.* 1991, Clarion Books.

Verba, J. *Voyager: Exploring the Outer Planets.* 1991, Lerner Publications.

Vogt, G. *Jupiter.* 1993, Millbrook Press/ Houghton Mifflin.

Grades 7-9

Davis, D. & Peterson, C. *Jupiter.* 1989, Facts on File.

Branley, F. *Jupiter: King of the Gods, Giant of the Planets.* 1981, Dutton.

Taylor, G. *Vocanoes in the Solar System.* 1983, Dodd Mead. Includes a section on Io.

Radlauer, R. & Young, C. *Voyagers 1 & 2: Robots in Space.* 1987, Children's Press.

SELECTED AUDIOVISUAL MATERIALS

And Then There Was Voyager (30-min 1992 video, NASA/Finley-Holiday Films/ Astronomical Society of the Pacific) A summary film of all the stops on the Voyager mission.

Galileo's Four (software for IBMs from Zephyr Services) Calculates and shows the positions of Jupiter's four large moons at any time.

Jupiter (a set of 20 slides from Finley Holiday Films) Inexpensive slide set with good images from Voyager.

Traveler's Tales (an episode of Carl Sagan's 1980 TV series *Cosmos,* Turner Home Video) Beautifully produced video on the exploration of Jupiter and Saturn.

Voyager Gallery (videodisc from Optical Data Corp.) Includes thousands of Voyager images.

Many of the slide distributors listed in the resources section have slide sets taken from the Voyager images, including Hansen Planetarium, Science Graphics, etc.

Also see the *Planetary System* and *Worlds In Comparison* slide sets under the "Solar System in General" resources.

6. SATURN

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

- Morrison, D. *Voyages to Saturn.* 1982, NASA Special Publication SP-446, available from the U. S. Government Printing Office. The definitive non-technical book on Saturn after the Voyager missions, by an astronomer.
- Washburn, M. *Distant Encounters: The Exploration of Jupiter and Saturn.* 1983, Harcourt, Brace, Jovanovich. A fine guide to the Voyager encounters and results by a journalist.

Rothery, C. *Satellites of the Outer Planets.* 1992, Oxford U. Press. A geologist examines the moons in the outer solar system.

Croswell, K. "The Titan-Triton Connection" in *Astronomy,* Apr. 1993, p. 26. Titan is the large satellite of Saturn with an atmosphere.

Cuzzi, J. "Ringed Planets: Still Mysterious" in *Sky & Telescope,* Dec. 1984, p. 511; Jan. 1985, p. 19.

Esposito, L."The Changing Shape of Planetary Rings" in *Astronomy,* Sep. 1987, p. 6.

- Gore, R. "Saturn: Lord of the Rings" in *National Geographic*, July 1981.
- Morrison, D. "The New Saturn System" in *Mercury*, Nov/Dec. 1981, p. 162.

Murrill, M. "Voyager: The Grandest Tour" in *Mercury*, May/June 1993, p. 67. Clear summary of all the Voyager encounters.

O'Meara, S. "Saturn's Great White Spot Spectacular" in *Sky & Telescope*, Feb. 1991, p. 144. On the observations of an enormous storm on Saturn with the Hubble Space Telescope.

- Overbye, D. "The Lord of the Rings" in *Discover*, Jan. 1981, p. 24.

Sanchez-Lavega, A. "Saturn's Great White Spots" in *Sky & Telescope*, Aug. 1989, p. 141.

Smith, B. "Voyage of the Century" in *National Geographic*, Aug. 1990, p. 48. Beautiful summary of the entire Voyager mission.

Sobel, D. "Secrets of the Rings" in *Discover*, Apr. 1994, p. 86. On the ring systems of all the outer planets.

Reports on the Voyager encounters with Saturn appeared in the Nov. and Dec. 1981 issues of *Astronomy* magazine, and the Oct. and Nov. 1981 issues of *Sky & Telescope*.

SELECTED READINGS FOR STUDENTS

Grades 4-6

Asimov, I. *Saturn: The Ringed Beauty*. 1989, Gareth Stevens.

Branley, F. *Saturn: The Spectacular Planet*. 1983, Crowell.

Fradin, D. *Saturn*. 1989, Children's Press.

Vogt, G. *Saturn*. 1993, Millbrook Press.

Walz-Chojnacki, G. "Excuse Me: Saturn Burped" in *Odyssey*, 1991, issue 3, p. 16. On the big storm observed with the Hubble Space Telescope.

Ride, S. & O'Shaugnessy, T. *Voyager: An Adventure to the Edge of the Solar System*. 1992, Crown. Written by America's first woman in space and a science teacher, for the younger grades.

Harris, A. & Weissman, P. *The Great Voyager Adventure*. 1990, Julian Messner.

Apfel, N. *Voyager to the Planets*. 1991, Clarion Books.

Verba, J. *Voyager: Exploring the Outer Planets*. 1991, Lerner Publications.

Grades 7-9

Davis, D. & Halliday, I. *Saturn*. 1989, Facts on File.

Radlauer, R. & Young, C. *Voyagers 1 & 2: Robots in Space*. 1987, Children's Press.

SELECTED AUDIOVISUAL MATERIALS

And Then There Was Voyager (1992 NASA video, Finley Holiday Films or the Astronomical Society of the Pacific) A summary film of all the stops on the Voyager mission.

Saturn: Voyager 1 and Saturn: Voyager 2 (sets of 40 slides plus cassettes of narration from Finley Holiday Films)

Voyager Gallery (videodisc from Optical Data Corp.) Has thousands of Voyager images.

Voyager: Missions to Jupiter and Saturn (1983 video, NASA) 20 minute summary video, with nice footage.

Slide sets of the Saturn system have also been available from Hansen Planetarium, Holiday Films, and the Planetary Society.

Also see the *Planetary System* and *Worlds In Comparison* slide sets under the "Solar System in General" resources.

7. URANUS

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

- Davis, J. *Flyby*. 1987, Atheneum. Excellent jour-

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nalist's account of the Voyager 2 flyby of Uranus and what was learned.

• Miner, E. *Uranus.* 1990, Ellis Horwood/Simon & Schuster. Definitive account of the Voyager flyby and the Uranus system by one of the principal scientists.

Littmann, M. *Planets Beyond: Discovering the Outer Solar System*, 2nd ed. 1989, John Wiley. A nice introduction to the history and current understanding of the 3 outermost planets.

Rothery, D. *Satellites of the Outer Planets.* 1992, Oxford U. Press.

Bennett, J. "The Discovery of Uranus" in *Sky & Telescope*, Mar. 1981, p. 188.

• Cowling, T. "Big Blue: The Twin Worlds of Uranus and Neptune" in *Astronomy*, Oct. 1990, p. 42.

• Gore, R. "Uranus: Voyager Visits a Dark Planet" in *National Geographic*, Aug. 1986.

Elliott, J., et al. "Discovering the Rings of Uranus" in *Sky & Telescope*, June 1977, p. 412. The discoverer's own words.

Murrill, M. "Voyager: The Grandest Tour" in *Mercury*, May/June 1993, p. 67. Clear summary of all the Voyager encounters.

Morrison, N. "A Refined View of Miranda" in *Mercury*, Mar/Apr. 1989, p. 55.

• Overbye, D. "Voyager Was on Target Again" in *Discover*, Apr. 1986, p. 70.

Smith, B. "Voyage of the Century" in *National Geographic*, Aug. 1990, p. 48. Good summary of the entire Voyager mission.

Detailed coverage of the Voyager flyby of Uranus and its satellites can be found in the April and October 1986 issues of *Sky & Telescope*, and in the April and May 1986 issues of *Astronomy*.

SELECTED READINGS FOR STUDENTS

Grades 4-6

Asimov, I. *Uranus: The Sideways Planet.* 1988, Gareth Stevens.

Branley, F. *Uranus: The Seventh Planet.* 1988, Crowell.

Ardley, N. *The Outer Planets.* 1987, Schoolhouse Press.

Ride, S. & O'Shaugnessy, T. *Voyager: An Adventure to the Edge of the Solar System.* 1992, Crown. Written by America's first woman in space and a science teacher, for the younger grades.

Harris, A. & Weissman, P. *The Great Voyager Adventure.* 1990, Julian Messner.

Apfel, N. *Voyager to the Planets.* 1991, Clarion Books.

Verba, J. *Voyager: Exploring the Outer Planets.* 1991, Lerner Publications.

Vogt, G. *Uranus.* 1993, Millbrook Press.

Krumenaker, L. "The Discovery of Uranus' Rings" in *Odyssey*, 1992, issue 4, p. 40.

Grades 7-9

Davis, D. & Yeomans, D. *Distant Planets.* 1989, Facts on File.

Radlauer, R. & Young, C. *Voyagers 1 & 2: Robots in Space.* 1987, Children's Press.

SELECTED AUDIOVISUAL MATERIALS

Uranus: I Will See Such Things. (1987 video, NASA/Finley-Holiday Films or the Astronomical Society of the Pacific). Excellent half-hour summary of the Voyager encounter; the ASP tape also has *Miranda: The Movie*, a computer generated "fly-over" of the odd moon Miranda.

The Planet That Got Knocked on Its Side (1987 video, Coronet Films) An episode of the NOVA public television series on the Voyager flyby.

And Then There Was Voyager (1992 video, NASA/Astronomical Society of the Pacific) A summary film of all the stops on the Voyager mission.

On Robot Wings: A Flight Through the Solar System (1992 video, NASA/Finley-Holiday Films) Includes *Miranda: The Movie.*

Voyager at Uranus (1986 slide set, Astronomical Society of the Pacific) 15 slides and a 20-page booklet.

Voyager Gallery (videodisc from Optical Data Corp) Has thousands of Voyager images from the Jupiter, Saturn, and Uranus encounters, but not Neptune.

Voyager 2 Uranus Encounter (set of 20 slides from Finley Holiday Films)

Also see the *Planetary System* and *Worlds In Comparison* slide sets under the "Solar System in General" resources.

8. NEPTUNE

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

- Littmann, M. *Planets Beyond: Discovering the Outer Solar System*, 2nd ed. 1989, John Wiley. A nice introduction to the history and current understanding of the 3 outermost planets.

Burgess, E. *Far Encounter: The Neptune System.* 1991, Columbia U. Press. A summary of the Voyager mission and its results.

Rothery, D. *Satellites of the Outer Planets.* 1992, Oxford. U. Press. A geologist summarizes what we know about the moons of the giant planets.

- Cowling, T. "Big Blue: The Twin Worlds of Uranus and Neptune" in *Astronomy*, Oct. 1990, p. 42.

Croswell, K. "The Titan/Triton Connection" in *Astronomy*, Apr. 1993, p. 26. About similarities among the worlds in the outer solar system.

Croswell, K. "To The Edge: Missions to Pluto and Neptune" in *Astronomy*, May 1992, p. 34. Possible future missions to the outermost planets.

Drake, S. & Kowal, C. "Galileo's Sighting of Neptune" in *Scientific American*, Dec. 1980.

- Gore, R. "Neptune: Voyager's Last Picture Show" in *National Geographic*, Aug. 1990, p. 35.

Limaye, S. "Neptune's Weather Forecast: Cloudy, Windy, and Cold" in *Astronomy*, Aug. 1991, p. 38.

Kaufmann, W. "Voyager at Neptune" in *Mercury*, Nov/Dec. 1989, p. 174.

Moore, P. "The Discovery of Neptune" in *Mercury*, Jul/Aug. 1989, p. 98. A nice historical summary.

- Smith, B. "Voyage of the Century" in *National Geographic*, Aug. 1990, p. 48. Good summary of the entire Voyager mission.

Coverage of the Voyager Neptune encounter was in *Sky & Telescope*, Oct. 1989 (p. 358) and Feb. 1990 (p. 136); and *Astronomy*, Nov. 1989 (p. 20) and Dec. 1989 (p. 22).

SELECTED READINGS FOR STUDENTS

Grades 4-6

Asimov, I. *Neptune: The Farthest Giant.* 1990, Gareth Stevens. Good introduction, written after the Voyager encounter.

Ride, S. & O'Shaugnessy, T. *Voyager: An Adventure to the Edge of the Solar System.* 1992, Crown. Written by America's first woman in space and a science teacher, for the younger grades.

Harris, A. & Weissman, P. *The Great Voyager Adventure.* 1990, Julian Messner.

Apfel, N. *Voyager to the Planets.* 1991, Clarion Books.

Verba, J. *Voyager: Exploring the Outer Planets.* 1991, Lerner Publications.

Vogt, G. *Neptune.* 1993, Millbrook Press.

Grades 7-9

Davis, D. & Yeomans, D. *Distant Planets.* 1989, Facts on File.

SELECTED AUDIOVISUAL MATERIALS

And Then There Was Voyager (1992 NASA video, Astronomical Society of the Pacific or Finley-Holiday Films) A summary film of all the stops on the Voyager mission.

The Neptune Kit (1990 slide set, Astronomical Society of the Pacific) 12 slides from the Voyager encounter with a 32-page booklet of captions and background information.

Voyager at Neptune (set of 20 slides, Finley-Holiday Films)

Voyager Neptune Encounter Highlights (1990 video, Astronomical Society of the Pacific) A collection of 21 short films from the flyby of the Neptune system.

9. PLUTO

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

Tombaugh, C. & Moore, P. *Out of the Darkness: The Planet Pluto.* 1980, Stackpole Books. By the planet's discoverer; gives the history of our learning about Pluto.

Hoyt, W. *Planets X and Pluto.* 1980, U. of Arizona Press. The history from a more scholarly perspective, by a historian.

- Littmann, M. *Planets Beyond: The Outer Solar System,* 2nd ed. 1990, John Wiley. A good summary of our current understanding.

Levy, D. *Clyde Tombaugh: Discoverer of Pluto.* 1991, U. of Arizona Press. An admiring biography.

Beatty, J. & Kilian A. "Discovering Pluto's Atmosphere" *Sky & Telescope,* Dec. 1988, p. 624.

Binzel, R. "Pluto" in *Scientific American,* June 1990.

- Burnham, R. "At the Edge of Night: Pluto and Charon" in *Astronomy,* Jan. 1994, p. 41.
- Croswell, K. "Pluto: Enigma at the Edge of the Solar System" in *Astronomy,* July 1986, p. 6.

Croswell, K. "To the Edge: Missions to Pluto and Neptune" in *Astronomy,* May 1992, p. 34.

Harrington, R. & B. "The Discovery of Pluto's Moon" in *Mercury,* Jan/Feb. 1979, p. 1.

Moore, P. "The Naming of Pluto" in *Sky & Telescope,* Nov. 1984, p. 400.

Tombaugh, C. "The Discovery of Pluto" in *Mercury,* May/Jun. 1986, p. 66 and Jul/Aug. 1986, p. 98. The story as told by the discoverer.

SELECTED READINGS FOR STUDENTS

Grades 4-6

Asimov, I. *Pluto: A Double Planet?* 1990, Gareth Stevens.

Levy, D. "Clyde Tombaugh: The Man Who Found Pluto" in *Odyssey,* 1992, issue 4, p. 14.

Grades 7-9

Davis, D. & Yeoman, D. *Distant Planets.* 1989, Facts on File.

SELECTED AUDIOVISUAL MATERIALS

The Discovery of Pluto (1983 video, Astronomical Society of the Pacific) Interviews with and narration about Clyde Tombaugh.

Cosmic Clips (1993 video, Astronomical Society of the Pacific) Short videos collection, including an animation of Pluto and its satellite Charon, during the 1985-89 eclipse season.

Many slide sets featuring images from the Hubble Space Telescope will include one of Pluto and Charon.

D

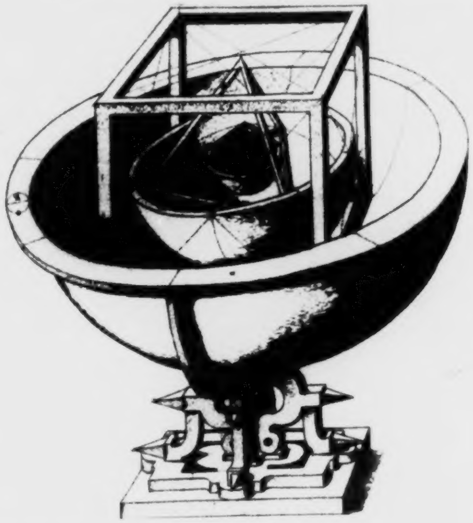
SCALE OF THE SOLAR SYSTEM

ACTIVITIES INCLUDED IN SCALE OF THE SOLAR SYSTEM

ACTIVITY	ESTIMATED GRADE LEVEL											
Grades	1	2	3	4	5	6	7	8	9	10	11	12
D-1. A Question of Scale Students match their estimates of the sizes of objects and the distances between objects with points along a distance scale.				▨	■	■	■	■	■	▨		
D-2. A 3-D Model of the Earth and Moon Students make balls of clay to model the relative sizes and distance apart of the Earth and Moon.					■	■	■	■	■	▨		
D-3. How Big is the Moon? Students observe the Moon through a circular hole, and determine the size of the Moon based on its known distance from Earth								■	■	■	■	■
D-4. Finding the Size of the Sun and Moon Students find the sizes of the Sun and Moon using a pinhole to project the images.								■	■	■	■	■
D-5. Solar System Scale Model Sized to Your Room Students use the longest available distance to set up a scale model of the solar system.			▨	▨	▨	▨	■	■	■	■	▨	▨
D-6. Toilet Paper Solar System Scale Model Students use a roll of toilet paper to create a scale model of the solar system.			▨	▨	▨	■	■	■	■	■	▨	▨
D-7. The Thousand-Yard Model Using common objects, students create a scale model of the solar system which includes the relative sizes of the planets.			▨	■	■	■	■	■	■	■	■	■
D-8. Extraterrestrial Excursions Students calculate how long it would take them to reach the Moon and planets, if they traveled in a rocket, and their age on arrival.				■	■	■	■	▨	▨	▨		
D-9. Time Traveler Students walk heel-to-toe for a minute and use the distance they travel as an analogy to the light-year as a unit of distance.						■	■	■	■	▨	▨	

■ - Grade levels recommended by authors ▨ - Can be extended to these grade levels

About the Activities:
Scale of the Solar System



KEY IDEAS IN "SCALE OF THE SOLAR SYSTEM"

- Concepts about the scale of the solar system are crucial prerequisites for understanding the nature of astronomical objects.
- Activities are important in communicating concepts of scale because many students at all grade levels have difficulty comprehending the sizes of planets and stars compared with everyday objects.
- The *Benchmarks for Science Literacy* suggests that this topic is most appropriate for students in grade 6 and above, and goes on to recommend activities such as those included in this section, in which students create scale models of the solar system using the same scale factor for size and distance.
- Recommended extensions for grades 9-12 include light years and the use of large numbers.

How big is space? How long would it take to drive to the Moon? If the Sun were the size of a grapefruit, how big would the Earth be? How can we measure the size of the Sun or Moon using geometry? These are just some of the very common questions students at all grade levels ask when they start to discuss astronomy. Addressing these questions not with lectures, but with activities can help "hook" the students on astronomy, and encourage them to develop concepts, skills, and positive attitudes toward science.

We start with activities about the scale and structure of the solar system and space because these concepts are crucial for students' understanding of the nature of astronomical objects. Our understanding of the Moon, for example, is quite different if we imagine it to be just beyond our reach, rather than a quarter of a million miles away!

Another reason for starting with these activities is because students at all grade levels often have difficulty comprehending how big space really is, and how large the planets and stars are compared with everyday objects. The activities in this section will help to prepare your students for further investigations of the planets, stars, and galaxies.

The *Benchmarks for Science Literacy* offers some guidelines in teaching this subject. For grades 5-6, it suggests that students "not invest much time in trying to get the scale of distances firmly in mind." (*Benchmarks*, page 62) This is because most children's cognitive abilities at this age level are not yet sufficiently mature to envision the vast sizes and distances involved. It is too far from their personal experiences.

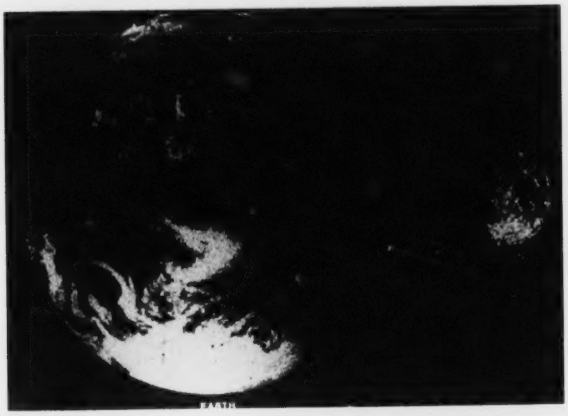
In grades 6-8, however, the *Benchmarks* recommends that scale and structure form a focus on the astronomy curriculum. "Students should add more detail to their picture of the universe, pay increasing attention to matters of scale, and back up their understanding with activities using a variety of astronomical tools.....Figuring out and constructing models of size and distance—for example, of the planets within the solar system—is probably the most effective kind of activity. Models with three dimensions are preferable to pictures and diagrams. Everyone should experience trying to fashion a physical model of the solar system in which the same scale is used for the sizes of the objects and the distances between them (as distinct from most illustrations, in which distances are underrepresented by a factor of 10 or more.)" (*Benchmarks*, page 63)

At the 9-12 grade level, if students have not had the above experiences, it is not too late! Even college students can benefit from some of the activites included in this section if they have not yet had a chance to do so. In addition, the *Benchmarks* recommends that at the 9-12 grade level, "The scale of billions will make better sense, and the speed of light can be used to express relative distances conveniently." (*Benchmarks*, page 65.)

Activity 1, "A Question of Scale," from the Lawrence Hall of Science, makes a very nice assessment activity, especially when students can first view the video "Powers of Ten" (see the Resource list at the end of this section). Activities 2-4 involve students in using geometry to find out how astronomers have discovered sizes and distances in the solar system.

Activities 5-7 in this section are variations of a classic exercise, recommended by the *Benchmarks*, in which teachers and students create a scale model of the solar system in the classroom or on school grounds. For younger grades, just the distances between the planets can be scaled. For older students, both the distances and sizes of the planets can be created with the same scale factor, using common objects such as pebbles or peppercorns to represent the planets.

Activities 8 and 9 introduce students to the relationship between time and distance in the vast reaches of outer space. These activities can be extended for students at the 9-12 age level with more information on the speed of light, the concept of "light years" as distances, and discussion of the size or expansion of the universe.



BACKGROUND:
SCALE OF THE SOLAR SYSTEM

One major problem with astronomy is that our everyday experiences don't prepare us to think about the distances and sizes of the planets, stars, galaxies and the universe as a whole. If we do try to talk about them, the numbers quickly become, well, astronomical. So we try to relate astronomical numbers to our everyday experiences, moving from familiar distances and sizes to larger ones; we scale astronomy to things we can understand.

How big is the Earth? If you travel once around the Earth along the equator, you would go 25,000 miles. But what does that mean? How big is 25,000 miles? Think of the United States—2500 miles across. Perhaps you've driven across the country at some time in your life. How long did it take you to get from New York to Los Angeles? Maybe four or five days of long, hard driving, if you don't stop except to eat and sleep. Most people find it an exhausting trip. How big is the Earth? You could wrap ten US's around the Earth's equator. Imagine 40 to 50 days of long, hard driving (at the speed limit) just to go once around the Earth! Now you're getting a feel for the size of the Earth.

Well then, what about the distance from the Earth to the Sun? It's 93 million miles, but what does that really mean? How big is a million anyway? Probably the fastest most of us have ever moved is when we fly in an airplane. A 747 jumbo jet flies at about 600 miles an hour, taking us across the US in a few hours. If we could take our 747 to the Sun (we can't because there is no atmosphere in space), how long do you think it would take to get there? A few days? A few months? A year? Actually it would take almost 17 years to fly in a 747 from the Earth to the Sun! And that's still a relatively short distance in the solar system.

As we move farther away from the Earth, distances quickly get so large that even relative scales like the ones above begin to require unfathomable numbers. So astronomers use a shorthand involving the fastest speed possible, the speed of light. Light moves through space at 186,000 miles each second (300,000 kilometers each second). Have you ever seen someone chopping wood in the distance? You see the ax hit the tree, but it's a second or so before you hear the sound. That's because the speed of light is faster than the speed at which the sound travels. Remember how big the Earth is? Well, light circles the Earth 7 and 1/2 times in just one second!

It takes light one-and-a-half seconds to go from the Earth to the Moon, a distance of about

240,000 miles. Those of you old enough to have watched the Moon landings on TV may remember the time delay in communication between Mission Control and the astronauts walking on the Moon, caused by the time it took radio waves, moving at the speed of light, to get from here to there and vice versa. It takes light about eight minutes to go from the Earth to the Sun, the same distance it took our 747 seventeen years to travel. If the Sun suddenly "turned off," we wouldn't know for eight minutes!

Astronomers thus speak of distances in terms of how long it would take light to travel them. We do this sort of thing in everyday life too. If someone asks you how far away Los Angeles is from San Francisco, you might answer, "a day's drive." You're using a unit normally associated with time to refer to a distance. Similarly, we could say that the Sun is eight light-minutes away from Earth. Pluto is five light-hours away, since it takes light five hours to get from Pluto to Earth. A light year is defined as the distance that light, moving at 186,000 miles every second, travels in a year. It corresponds to about 6 trillion miles, an unimaginably big number. A string one light year long would wind around the equator of the Earth 236 million times!

When we get out of the solar system, the distances involved become truly astronomical. The nearest star, named Proxima Centauri, is a little over 4 light years away! Putting this in another context, if the Sun were a large grapefruit in Washington, DC., Proxima Centauri would be a cherry somewhere in California. The Earth would be smaller than the head of a pin (1.3 mm in diameter) and 50ft. (15m) from the grapefruit-sized sun. The center of our galaxy is some 27,000 light years from us. The next nearest large galaxy, called M31, is two million light years away. (To give the distance to M31 in miles, you'd have to write the number 12 followed by 18 zeroes! Not very practical.)

Earlier, we talked about how big the Earth seems in terms of our everyday experiences. In an astronomical sense, however, the Earth is really quite small, even within the solar system. For example, you could fit 1000 Earths inside Jupiter, the largest planet. And you could fit 1000 Jupiters inside the Sun. Planets are tiny compared to stars. One million Earths would fill the Sun! And the Sun is really a rather small star. The giant star Betelgeuse (which marks the shoulder of the constellation Orion the Hunter) is so large that one million Suns could fit inside it!

One consequence of the immense distances between objects in the universe is that the farther out you look, the further into the past you can see. To "see" an object means that light from that object has entered your eye. Seeing a distant object in the universe (say a galaxy 100 million light years away) means that light from that object has been traveling for a long time to get to your eye (100 million years to be precise). This means you are "seeing" the object as it was back when the light was given off—100 million years ago. In essence, whenever you look out into the universe, you are looking back in time. Even the light from our neighbor star Alpha Centauri takes about four years to reach us; thus, when we look at that star, we are only seeing what it looked like four years ago. If something unusual happened on Proxima Centauri's surface right now, we wouldn't know about it until four years from now!

In one sense, this may seem frustrating—astronomy is always a little like ancient history. But what at first seems like a curse is actually a blessing in disguise. By looking at distant objects (and thus far back in time), we can begin to reconstruct the history of the universe and to piece together how it evolved to make creatures like us possible.

Note: This article is based on a talk by Jeff Goldstein, from the Air and Space Museum, at the ASP's 1993 Annual Meeting.

A QUESTION OF SCALE

ACTIVITY D-1

GRADE LEVEL: 5-9

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What's This Activity About?

This is an excellent activity to prepare students to create solar system scale models, and a powerful way to investigate the preconceptions students have about astronomical distances. This is also a good activity to develop students' abilities to make reasonable estimates, a skill that is used in many scientific and commercial careers.

What Will Students Do?

Students cut out descriptions of various objects and distances, and attempt to match those descriptions to an actual metric measurement.

Tips and Suggestions

- This activity is an excellent complement to the film *Powers of Ten* by Charles and Ray Eames. (Available through the ASP catalog.)
- A colorful book based on the video, also called *Powers of Ten*, is published by the Scientific American Library and W.H. Freeman Co.
- Try adding familiar items and deleting objects with which students may not be familiar.
- Ask students to measure or estimate other items and include them in their tables, such as their classroom, their schools, their towns or cities, etc.

What Will Students Learn?

Concepts
Estimation of distances

Inquiry Skills
Measuring
Comparing
Ordering

Big Ideas
Scale
Models and Simulations

A Question of Scale

After seeing the video *Powers of Ten*, students think about the sizes of different things in the universe. In this activity, they try to place various objects on a metric "powers of 10" scale.

Materials

- ☐ "Question of Scale" worksheet (1/student; master on page 27)
- ☐ Pair of Scissors (1/student)
- ☐ Tape (1 for every group of 3 or 4 students)

Before Class

1. Photocopy a worksheet for each student
2. Using a paper cutter, cut the worksheets along the dotted line. [Students will cut dashed lines.]
3. It's best to do this activity after the class has seen the video "Powers of Ten."

In Class

1. Hand out worksheets and lists of challenge objects.
2. Have students cut each challenge object from the list with scissors and tape it to the appropriate place on the distance scale. Give them several minutes to do this. Allow them to consult each other and get opinions from friends.
3. Conclude activity with a vote of where each object goes. Then give typical distances and sizes from the list below. Discuss the difference between *distance* and *size*.

Distances to quote in *A Question of Scale*

width of a light switch lever	**about 1 cm**
ping pong ball	**about 3 cm**
softball	**about 10 cm**
basketball	**about 30 cm**
width of a door	**about 1 m**
height of doorway	**2+ m**
the classroom	**about 6 m?**
the school	**about 100 m?**
depth of the Grand Canyon	**over 1 km**
height of Mt Everest	**8.78 km**
deepest depth of Pacific Ocean	**11 km**
Denver to Kansas City	**890 km**
length of California	**1000 km**
Nashville to New York City	**1,213 km**
diameter of Moon	**3,476 km**
San Francisco to New York	**4,100 km**
diameter of Earth	**12,756 km**
diameter of Jupiter	**142,800 km**
distance to the Moon	**384,402 km**
diameter of the Sun	**1.4 million km**
distance to the Sun	**152 million km**
distance from Sun to Saturn	**almost 1.5 billion km**
nearest star (other than Sun)	**38 million million km — off the scale**
Milky Way galaxy	**100,000 LY or a million billion km — way off the scale**

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A Question of Scale

1 cm

10 cm

1 meter

10 meters

100 meters

1 km

10 km

100 km

1000 km

10,000 km

100,000 km

1 million km

10 million km

100 million km

1 billion km

basketball

classroom

deepest depth of Pacific Ocean

Denver to Kansas City

depth of the Grand Canyon

distance of Sun from Earth

Earth to Moon distance

Earth's diameter

height of a doorway

height of Mt. Everest

Jupiter's diameter

length of California

Milky Way galaxy

Moon's diameter

Nashville to New York City

nearest star (other than Sun)

ping pong ball

San Francisco to New York

softball

Sun to Saturn

Sun's diameter

the school

width of a door

width of a light switch lever

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A 3-D MODEL OF THE EARTH AND THE MOON

ACTIVITY D-2

GRADE LEVEL: 5-9

Source: By David Abbott, Nederland Elementary School, Boulder, Colorado. Reprinted by permission.

What's This Activity About?

Another method to demonstrate the scale of our Solar System to students is to have them construct models out of clay. This activity was chosen because it incorporates the concept of volume, and it has some interesting supplementary facts, including how scientists measure the Earth-Moon distance today.

What Will Students Do?

Students create 50 balls of clay, and use one to represent the Moon. They combine the remainder to represent the Earth. The students then use these accurately scaled balls to model the Earth-Moon distance.

Tips and Suggestions

- Ask the students to experiment further by weighing the large clay ball (the Earth) and the small clay ball (the Moon) and checking the ratio of their masses. Then ask questions about how much the Earth would weigh if it contained heavier materials than clay. (It would have a greater mass for the same size, or a larger density.) The Earth's core is made of iron and nickel, which are much heavier than the materials in our planet's mantle. This is why our planet's overall mass is closer to 80 times that of the Moon.
- Have students work in groups or as a class to make the clay balls.

What Will Students Learn?

Concepts

- Diameter
- Volume
- Mass
- Density

Inquiry Skills

- Modeling
- Measuring
- Comparing

Big Ideas

- Scale Structure
- Matter
- Models and Simulations

A 3D Model of the Earth and the Moon

by David Abbott
1601 Mariposa Ave.
Boulder, CO 80302

Moon Facts:

- *Like the rest of the Solar System, the Moon is about 4 1/2 billion years old. Most of the cratering occurred in the first billion years of its life, when left-over debris from planet formation was plentiful.*
- *The same side of the Moon always faces the Earth. (The Moon's rotation rate is synchronous with its revolution about the Earth). This is because the Moon is somewhat lop-sided, and the gravitational force of the Earth eventually pulled on the Moon until its heavy side faces the Earth.*
- *Because of a loss of energy to tidal friction, the Moon is very gradually moving away from the Earth. In the early history of the Earth, the Moon was about 3 times larger in apparent size in the sky, because it was closer to the Earth.*
- *The "seas" of the Moon are really smoother and darker colored rock that came from volcanic flows early in the history of the moon, but after most of the cratering had occurred.*

Objectives:

- To allow students to experience a sense of scale in our Solar System.
- To provide information about the Moon.
- To use geometric math concepts, including ratio, volume, & diameter.

Introduction

Ask students, "If I could reach up and grab the Moon out of the sky and put it down here on Earth, how big would it be? As big as the school, Colorado, the United States, the Earth?"

Part I

Divide students into groups (3 or 4). Give each group of students a large ball of clay; each ball should be a different size. Ask them to divide it into 50 equal sized balls (for younger students, this can be a worth-while math problem by itself). Have them choose one ball that is "average" in size, and then combine the other 49 pieces back into a large ball. This is a scale replica of the Moon (the remaining little piece) and the Earth (the 49 pieces combined). Notice that each group has a different-sized Earth and Moon; it is the scale that is the same for everybody, including the real Earth and Moon.

Start a chart and fill in answers comparing the Earth and Moon:

Property	**Earth**	**Moon**
Volume	49	1

Students will recognize that it takes 49 Moons to fill 1 Earth; we just did it. Likewise, if the Earth and Moon were made of the same stuff, their mass would follow this ratio. (Actually, the Moon is similar throughout to the Earth's lower-density mantle, so the Earth is about 80 times the Moon's mass).

Part II

Ask students to predict the ratio of the Earth's diameter to that of the Moon. Ask them to measure their diameters to find out the answer. One way is to push a toothpick through the center of the clay ball, and then measure its length with a ruler. Record the answers for each group. Then divide the Earth's diameter by the Moon's. The answers should be grouped around 3.7 (calculators may be helpful here). Discuss why everyone's answer should be equal (same ratio), but the measurements all differed. Add this to the table:

Diameter 3.7 1

The Earth has a diameter of 12,734 km, and the Moon's diameter is 3,476 km. Thus, the Moon is about the same size as the United States. Discuss with students why the diameter is not in a ratio of 49 to 1. Volume goes as the cube of diameter.

Part III

Ask students to predict how far apart the Earth and Moon should be in their scale model system (if the Earth and Moon were really the size of their clay balls, how far apart would they be?). Encourage them to hold the Moon up to their Earth and try to visualize how far apart it should be. Each group must reach consensus, place its Earth/Moon set at that distance, and then measure the separation with a ruler or meter stick. Record all answers underneath their measured diameters. Note that each group will have a different correct answer, because they each have different sized Earth's. The correct answer is that the Earth/Moon separation is almost exactly 30 times the Earth's diameter. Ask students to calculate how close their prediction was to the actual distance.

✱ *The Moon has no atmosphere, because of its weak gravity (recall that the Moon has a mass 80 times smaller than the Earth). All types of gas will escape the Moon's gravity and be lost into space.*

✱ *Without air to modulate temperatures, the Moon's surface is about +300 F in its 2 week daytime and -270 F in its 2 week night. This despite the fact that the solar heating is the same on the Earth as on the Moon, because we are the same distance from the Sun.*

✱ *Without an atmosphere, there is no erosion. The Moon's surface is about the same now as it was 3 billion years ago. (Contrast to the Earth). The astronauts' footprints on the Moon's surface remain unchanged.*

✱ *The origin of the Moon is controversial. Currently, the favored theory is that in the early history of the Earth, an object roughly the size of Mars collided with the Earth, and the debris from this collision in orbit came together to form the Moon. This idea can explain why the composition of the Moon resembles that of the Earth's mantle.*

Students are generally amazed at how far apart the Earth and Moon are in their model. Ask them what the next closest object in space to the Earth is. The answer is Venus, at its closest approach in its orbit it is 41 million km away. This is 3000 Earth diameters! One hundred times further away than the Moon.

Moral

Space is very big. Even our closest neighbors in space are very large distances away. Even in our crowded neighborhood of space, the Solar System, space is mainly nothingness. (Of course there are a few particles of dust and rocks strewn throughout the space between planets, but space is still a better vacuum than anything we can create on Earth.)

Trivia

A University of Colorado scientist, Jim Faller, and co-workers measured the distance from the Earth to the Moon to an accuracy of 1 cm. He had the Apollo astronauts place a mirror on the Moon that reflected enough of a laser beam so he could measure the time for a round trip (about 1.5 sec.). Using the known speed of light, he could then calculate the distance to the Moon to an accuracy of one part in 100 million.

At the other extreme, note that the Space Shuttle orbits only 300 km above the Earth, which is roughly 1/40 of an Earth diameter. Even the high flying, geosynchronous satellites are only about 3 Earth diameters away.

HOW BIG IS THE MOON?

ACTIVITY D-3

GRADE LEVEL: 8-12

Source: Reprinted by permission from *Science Projects in Astronomy*. Copyright ©1990 by Bill Wickett. The full book is available from Science Projects in Astronomy, 1584 Caudor Street Encinitas, CA 92024. Cost: $10.95 + $3.50 shipping/handling.

What's This Activity About?

How can students use ratios to determine the size of our Moon? This is a simple activity, and good homework assignment to involve family members. By measuring the apparent size of the Moon, seen through a circle of known size, and using a length of string, you can easily determine the Moon's diameter (knowing its average distance is 384,000 kilometers).

What Will Students Do?

Students find a window at home or school where the full moon is visible. They cut out a paper circle, tape it on the window, and move away from the window until the moon is seen to be the same size as the paper hole. The students measures her/his distance from the paper with the string, and uses the ratio provided to determine the distance or diameter.

Tips and Suggestions

- It is important to note that the Moon orbits the Earth on an elliptical path, not circular, and at times is closer than 384,000 km and at other times is farther away.
- This activity can be done in the classroom during morning hours when the Moon is visible in its waning gibbous or third quarter phases. It will still be large enough to fill most of the paper circle.
- Scientists can find the Moon's average *distance* from Earth using many techniques, including applying Newton's Laws of motion or Kepler's Laws to relate its period of orbit around the Earth to its distance. Another method is to measure how long it takes a burst of laser light, sent from Earth and reflected by a mirror on the Moon, to travel to the Moon and back.

What Will Students Learn?

Concepts

- Earth-Moon distances
- Similar triangles and geometry

Inquiry Skills

- Measuring
- Calculating
- Visualizing

Big Ideas

- Scale
- Models and Simulations

HOW BIG IS THE MOON?

If you knew the moon is 384,400 kilometers from the Earth, could you figure out how big it is? Here's how:

WARNING: Don't try to measure the sun with this technique. Never look directly into the sun without an approved solar filter.

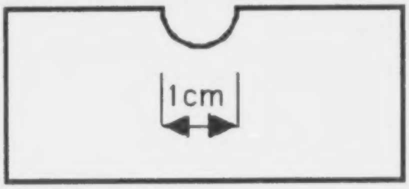
MATERIALS

Metric circle template, (can be purchased at an art store)
colored acetate
string
metric ruler

METHOD

To begin with, you must have a circle that is exactly one centimeter in diameter. You could cut one out of a 3 x 5 card, but a little mistake will cause a huge error in your final result. Play it safe and buy a circle template from an art store. They are used for drafting.

You'll find this project is much easier if you use half of a circle, so cut the template with scissors, exactly halfway through the circle. The final product should look like this:



Tape the template to a window that faces the moon when it is full. Use masking tape to cover any other holes, to avoid confusion. Tape about two meters of string to the window, right next to the circle. You'll use this string to measure the distance from the window to your eye.

Look through the circle at the moon. If it is too bright, use the acetate to darken its image. Move your head forward or backwards until the moon is exactly the size of the semicircle. This distance, between your eye and the card, is the distance you must measure.

Now pick up the string. Again position your head so that the moon just fills the hole. Pull the string tight, and hold it as close to your eye as possible. Don't let go! But move your head back, so you can measure the length of the string in meters. Be accurate! Your answer should be a bit more than one meter. Keep track of the exact distance, down to the millimeter.

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One of the special characteristics of a triangle is that its sides stay in proportion. The relationship between the length of the string and the size of the hole, is exactly the same as the relationship between the distance to the moon and the diameter of the moon.

For example, a 2 cm circle would have to be twice as far away as the one cm hole in the card. A 3 cm hole would be three times farther away.

The moon is 384,400,000 meters away. How many times longer is that, than the string? Use a calculator to divide 384,400,000 by the length of the string.

This answer is also the size of the moon! The only problem is that it's the diameter *in centimeters!* Divide by 100,000 to convert your answer back to kilometers. Be sure to demonstrate this conversion in your report.

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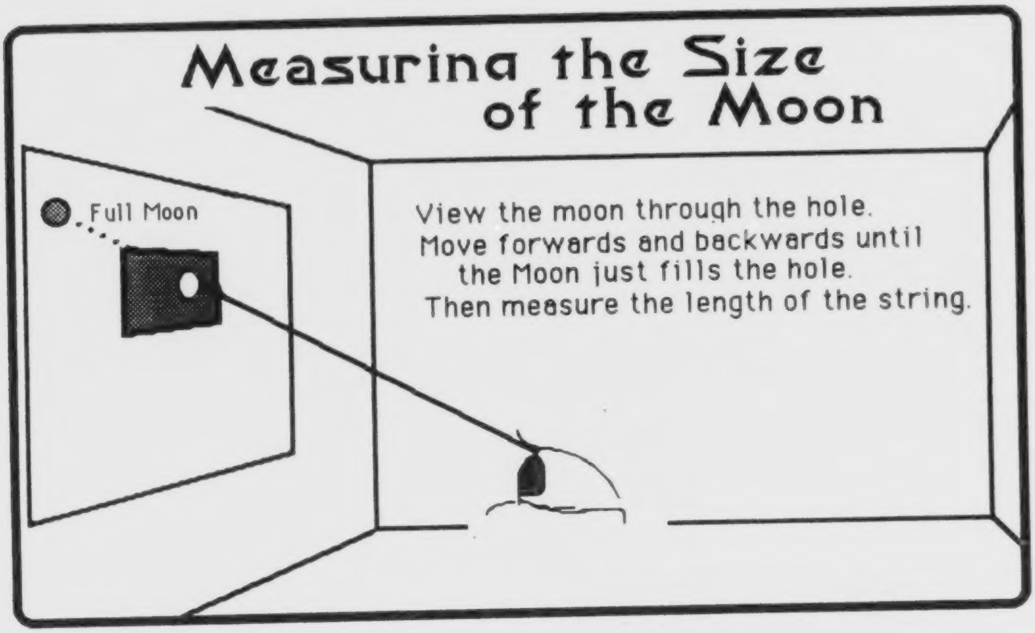
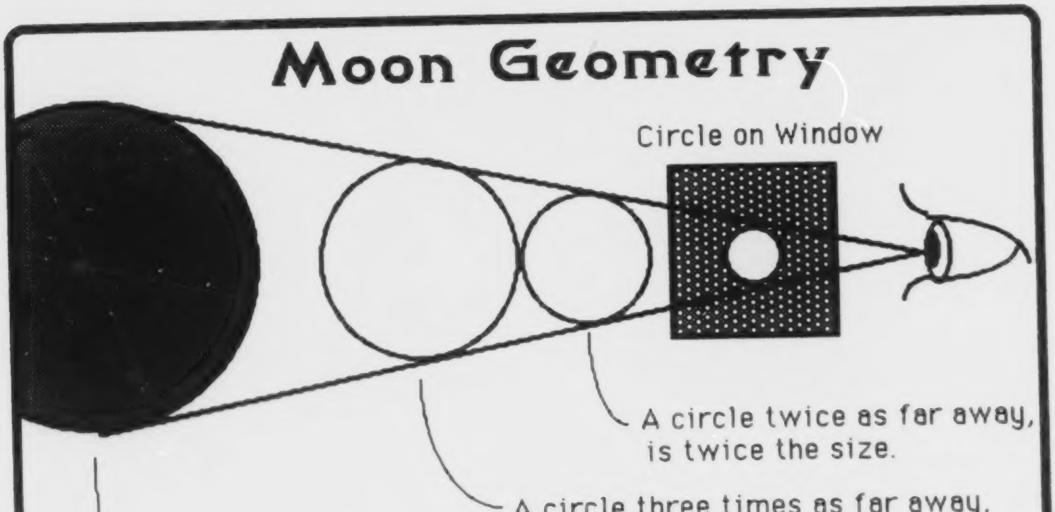
Measuring the Size of the Moon



View the moon through the hole.
Move forwards and backwards until
the Moon just fills the hole.
Then measure the length of the string.

Moon Geometry



A circle twice as far away,
is twice the size.

A circle three times as far away,
is three times the size.

How much bigger
is the moon?

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FINDING THE SIZE OF THE SUN AND THE MOON

ACTIVITY D-4

GRADE LEVEL: 8-12

Source: Reprinted by permission from *Living and Learning in the Space Age*, by Jeff Crelinsten. Copyright ©1988 by Fitzhenry & Whiteside Ltd., 195 Allstate Parkway, Markham, Ontario, L3R 4T8, Canada. Cost: $50.

What's This Activity About?

This is another activity about determining the size of astronomical objects using simple instruments and basic mathematics. The "pinhole camera" is used here to measure the sizes of the Sun or Moon. By projecting an image of a distant object through a pinhole in a piece of paper and measuring the image's size and distance from the pinhole, a simple ratio can be set up to determine the object's size, knowing its distance.

What Will Students Do?

Students place a pinhole in a piece of paper, and hold the paper up to the Sun or Moon light. The image of the Sun or Moon will be seen on a second piece of paper held behind the first. Students measure the size of the image and its distance from the pinhole, and determine the actual size of the celestial body.

Tips and Suggestions

- During the experiment, remind students not to stare directly at the Sun. The retina can be permanently damaged this way.
- You may be surprised how accurate this method is in predicting object sizes; it does not just work—it works well.
- Use the activity as an introduction to optics or in preparation for a solar eclipse, when pinhole cameras are especially useful for safe observation. Observing and measuring the Moon can be done at home as a family activity.
- Note that the distances provided in the activity are average distances only. Although we say the Sun's distance is 149,600,000 km (93 million miles), it varies because of the Earth's elliptical orbit from 147,000,000 km (92 million miles) to 153,000,000 km (about 94.5 million miles). Similarly, the Moon's average distance is 384,400 km.
- The formula for calculatintg the diameters is based upon similar triangles. In the diagram of the pinhole imaging:

$$\frac{\text{diameter of object}}{\text{diameter object to pinhole}} = \frac{\text{diameter of image}}{\text{distance image to pinhole}}$$

What Will Students Learn?

Concepts

Size of the Moon and the Sun
Similar triangles and geometry

Inquiry Skills

Measuring
Calculating
Imagining

Big Ideas

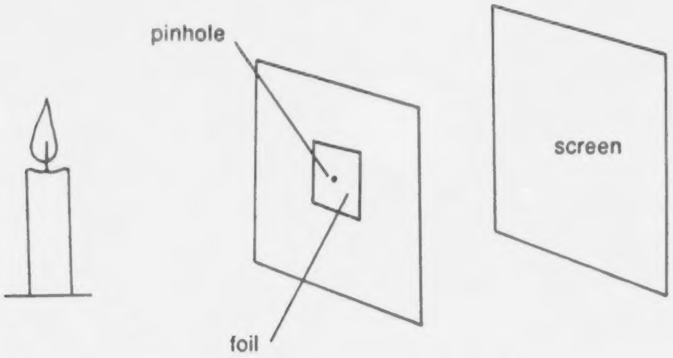
Scale

Finding the Size of the Sun and the Moon

In this activity you will measure the diameter of the sun and the moon. For the sun this will be the diameter of the light-producing part of the sun, the PHOTOSPHERE.

Materials sheet of cardboard
sheet of white paper
aluminum foil about 3 cm x 3 cm
pin or sharp point
tape
scissors
metric ruler
candle

(a) Make a pinhole camera as follows:
- Cut a square about 2 cm x 2 cm out of the centre of the cardboard.
- Place the aluminum foil over the opening and tape it in place at the edges of the foil.
- Puncture the foil to produce a small hole. You now have a pinhole camera.



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(b) To see that the pinhole can produce an image, set up the candle about ten centimetres away from one face of the pinhole camera.

- Light the candle.
- Turn out the lights in the room.
- Hold a white sheet of paper a few centimetres away from the opposite face of the pinhole camera. You should be able to see an image of the flame.
- What happens to the size of the image as you move the paper farther away?
- What happens to the size of the image as you move the candle farther away?

(c) Hold the pinhole camera so that the light from the sun passes through the hole and falls on a sheet of white paper held behind the hole. Try to make the distance between the pinhole and the paper as large as possible.

(d) Measure the distance between the pinhole and the paper and record:

diameter of image of sun = ________

(e) Measure the diameter of the image of the sun and record:
use the same units as for (d)

distance from pinhole to screen (paper) = ________

(f) On a clear night with a full moon, repeat steps (c) to (e) for the image of the moon.

diameter of image of moon = ______________

distance from pinhole to screen = __________

[Use the same units for these]

You can calculate the diameter of the sun using the following formula:

$$\text{sun's diameter} = \text{distance from Earth to sun} \times \frac{\text{diameter of image}}{\text{distance to screen}}$$

The distance from Earth to the sun is 149 600 000 km

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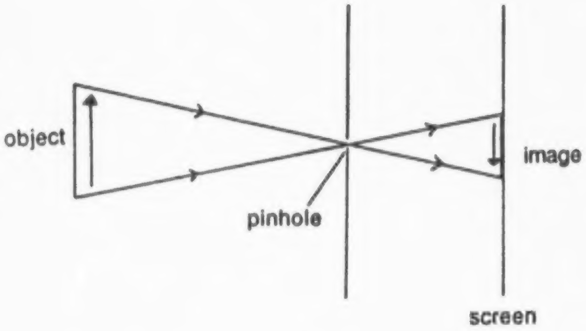
$$\text{moon's diameter} = \text{distance from Earth to moon} \times \frac{\text{diameter of image}}{\text{distance to screen}}$$

The distance from Earth to the moon is 384 400 km

Questions

1. How many times larger is the sun than the moon?

2. If the sun is so much larger, why does it not seem larger than the moon?



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SOLAR SYSTEM SCALE

ACTIVITY D-5

GRADE LEVEL: 7-10

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What's This Activity About

This activity is ideal if you do not have enough open space to use for a large solar system scale model. Like the toilet paper model (D-6), it is a good way to demonstrate the vast distances between planets, as well as the relative sizes, if desired. This activity is appropriate for middle and high school because it involves more mathematics in the calculation of scaling ratios.

What Will Students Do?

Students create a scale model of the solar system, based on a scale determined by the largest available distance in your school, which will represent the average Sun-Pluto distance. Students determine and/or measure the proper distances for all other planets based on that scaling factor.

Tips and Suggestions

- The activity has good preparatory and follow-up questions about creating models, an important concept for all sciences.
- This activity can take 1-2 hours for a moderately large scale, or just 1 hour if you use in-classroom or hallway distances.
- Link this activity with math lessons or a unit on scale and proportion.
- This activity requires additional time if your students have not worked much with scale. Plan to develop the scale factor one day and create the model the next day.
- For younger grades do a distance-only model. For older grades, include the planets' diameters.
- Have students create three-dimensional models of the planets, or make scale drawings with features.
- Have your students give a tour of "their solar system" to another class, families, or younger students.

What Will Students Learn?

Concepts

The relative spacing of the planets and their sizes

Inquiry Skills

Modeling
Measuring
Ordering

Big Ideas

Models and Simulations
Scale

Solar System Scale

Background

Sizes and distances in the Solar System are difficult to visualize. The distance from the Sun to Earth is 150 million km. The diameter of Jupiter is 140 thousand km. Both of these measurements are so much larger than anything you ever see that they are difficult to imagine. But there is another way of thinking about the Solar System that is much simpler. It involves reducing all the sizes by the same amount: for example, dividing all the sizes and distances by two. These new values can be used to make what is known as a **scale model**.

Examples of scale models are all around. Model railroads are scale models of trains. A globe is a scale model of Earth. Figure 1 on page 31 shows a scale model of the relative sizes of the planets, but their relative distances are not drawn to scale. The advantage of scale models is that they allow us to determine the distance and size of the true object. All that is needed is the **scaling factor** that was used in making the model. For example, if the wheels of a model car are 10 cm in diameter, and the wheels of a real car are 70 cm, then the scaling factor is 70 ÷ 10 or 7. Now, any size in the real car can be determined by looking at the model car. If the door of the model is 20 cm long, then the door of the real car is 20 × 7 or 140 cm long.

Johannes Kepler built a scale model of the Solar System almost 300 years ago using the best estimates for size and distance available at his time. As his base scale, he used what would later become known as the Astronomical Unit, the distance between the center of mass of the Sun and the center of mass of the Earth-Moon system. Once the true length of an AU was found (150 million km), the scaling factor could be determined and the rest of the distances calculated.

Procedure

1. Before starting this activity, picture in your mind what you think a scale model of the Solar System will look like and write a brief description of it. See if the model you build meets your expectations.
2. Measure the longest distance you can use, no more than 100 m. Measure this distance to the nearest meter and record it in Data Table 1. This distance will represent the

Objective

The objective of this activity is to build a scale model of the planetary distances in the Solar System.

Materials

For each group of students:

- ◊ about 100 m of string
- ◊ masking tape
- ◊ 10 flags
- ◊ measuring tape (30 meters or more preferably)
- ◊ marker

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distance between the Sun and the planet Pluto (that is 39.4 AU or 5.9 billion km).

3. To calculate the distance from the model sun to each model planet, you need to calculate a scaling factor. Determine the scaling factor by dividing the distance from step 2 above by the distance from the Sun to Pluto. Find this distance in Data Table 2. Record the scaling factor in Data Table 1. For example, if the longest distance usable is 78 m, then the scaling factor is 78 m ÷ 39.3 AU = 1.98 m/AU.
4. Multiply the scaling factor from step 3 by the actual distance from the Sun to each of the planets in AU. Use the distances in Data Table 2. Record the answer in the column labeled "scale distance from Sun."

DATA TABLE 1

Largest usable distance (meters)	Distance to Pluto (AU)	Scaling factor (m/AU)
	39.4	

DATA TABLE 2

Planet	Distance from Sun (AU)	Distance to planet (kilometers)	Scale distance from Sun (meters)	Actual diameter (kilometers)
Sun (a star)	n.a.	n.a.	n.a.	1,391,980
Mercury	0.39	58,000,000		4,880
Venus	0.72	108,000,000		12,100
Earth	1.00	150,000,000		12,800
Mars	1.52	228,000,000		6,800
Jupiter	5.20	778,000,000		142,000
Saturn	9.54	1,430,000,000		120,000
Uranus	19.2	2,870,000,000		51,800
Neptune	30.1	4,500,000,000		49,500
Pluto	39.4	5,900,000,000		2,300

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5. Measure out a length of string equal to the scale distance to Mercury from the Sun. Do not cut the string, but wrap a piece of masking tape around it at the proper distance and write "Mercury" on it. From that point, continue measuring the same string out to Venus, and mark that spot on the string. Continue doing this for all the planets out to Pluto.
6. Stretch the string out, and then attach a flag to the string at each point where the location of a planet is marked.

Questions and Conclusions

1. Describe what your model looks like. Is this different from what you pictured in your mind in step 1? If so, how?
2. The nearest star to Earth is Alpha Centauri, 274,332 AU away. Where would this star be placed in your scale model of Solar System distances?
3. What are some of the advantages and disadvantages that you see in using a scale model? Be specific and use examples from this activity.
4. If you were to make a scale model of the Milky Way Galaxy, what scaling factor might you use?

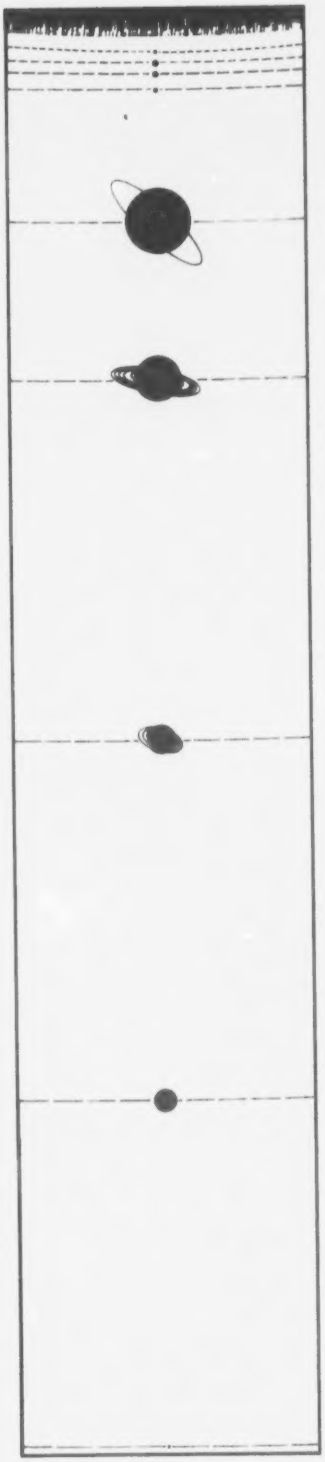

FIGURE 1

(Distances not to scale)

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TEACHER'S GUIDE TO ACTIVITY 3

Solar System Scale

Materials

For each group of students:

- ◊ about 100 m of string
- ◊ masking tape
- ◊ 10 flags
- ◊ measuring tape (preferably 30 meters or more)
- ◊ marker

Vocabulary

Scale model: A model that is proportional in all respects to the object being modeled.

Scaling factor: The factor or proportion which, when multiplied by measurements of a scale model, gives the measurements of the object.

Astronomical unit: The basic unit of length used to measure distances in the Solar System. It is the distance from the center of mass of the Sun to the center of mass of the Earth-Moon system (149,600,000 km).

What Is Happening?

Sizes and distances in the Solar System are extremely difficult to visualize. The distance from the Sun to Earth is 150 million km. The distance is so great that there is nothing in everyday experience with which to compare it. Working with distances of this magnitude is extremely difficult for students and adults alike.

One way of dealing with these distances is to use scale measurements, a form of indirect measurement. Many models of buildings and cars use scale measurements. In order to determine true measurements from scale models, one must only know the **scaling factor**. For instance, if a model car is one-seventh the size of the real car on which it is based, then every measurement on the real car is simply the scaling factor, seven, times the corresponding measurement on the model. If the wheels on the model are 10 cm in diameter, the real wheels are 10 cm × 7, or 70 cm.

In this activity, students will build a scale model of the Solar System using true measurements and a scaling factor. The model involves only the distances to the planets, not their sizes. In order to use the same scaling factor for both distance and size, a huge open area would be required. Without such a large area, the sizes of the planets would be much too small to see easily. This fact emphasizes one of the important features of the Solar System—it is mostly empty space. Students need to be made aware of another shortcoming of this model—it represents the planets as all being aligned on one side of the Sun. In reality, such an arrangement of the planets happens infrequently.

Important Points for Students to Understand

- ◊ The Solar System is largely empty space.
- ◊ A scale model is one way of working with distances that are too large to visualize.
- ◊ As long as the scaling factor is known, true measurements can be determined from scale measurements and vice-versa.
- ◊ The planets are rarely lined up on one side of the Sun.

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Time Management

This activity will probably take more than one class period but less than two. One option is to have the students do all their calculations and string measurement on the first day and then to have them actually lay out the full model on the second day.

Activity 4, "Hello, Out There!" uses the same Solar System scale you have just created. It takes less than a period, so you may want to schedule this at the end of the second day.

Preparation

If an outdoor space is being used, it is important to do the outdoor part of the activity on a day when the students will be comfortable outside for a long period of time. This activity can be done indoors either in a long hallway, the gymnasium, the cafeteria, the auditorium, or any other large open space.

For additional background information, refer to Reading 4, "Scale Measurements" and Reading 5, "Scouting Earth/Moon."

Suggestions for Further Study

Encourage students to calculate what the scale size of the planets would be using the same scaling factor as in the first part of the activity. Students may want to pursue the idea of finding a space large enough to lay out a scale model of the Solar System that does have actual models of the planets. An excellent exercise is to have them determine how large that space would be. At the very least, it would be several city blocks long. If such a space is easily accessible, building the model would be very instructive.

Groups of students can be assigned to research individual planets with regard to their important and unique features. Then, once the solar system is laid out, they can conduct a walking tour of the solar system, stopping at each planet to learn about it.

Suggestions for Interdisciplinary Reading and Study

Scale models are used in all aspects of Earth science—meteorology, geology, oceanography, and astronomy. The maps used in these areas can be scale models. In each case, the purpose of the model is to depict something which is very large in a much smaller size or something which is very small in a much larger size (like an atom, molecule, or mineral).

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Computer models have been particularly useful in meteorology in studying and predicting weather patterns. Many researchers are now trying to create models to study the greenhouse effect and global warming. They are attempting to use these models to predict the future effects of increased carbon dioxide in the atmosphere. These applications point out some of the advantages and disadvantages of models. Encourage students to investigate the use of models and how these models are different from scale models in other areas of Earth science.

The book *This Island Earth* (see Bibliography) provides descriptions of Earth as one of the nine planets in the Solar System. The accounts in the book emphasize the beauty and uniqueness of Earth among all the other planets (see Reading 5 for one such account).

The Solar System has been a source of inspiration for many authors. This is particularly true in science fiction and in poetry. Three examples of poems based on the Solar System are "The Planets" (beginning of Activity 3) by Myra Cohn Livingston and "A Distant Sun" (beginning of Activity 2) by Lydia Ferguson, and "Jewels" (beginning of Activity 5) by Myra Cohn Livingston.

Answers to Questions for Students

1. The inner planets are much closer together than the outer planets. The distance between planets increases as distance from the Sun increases. The model is mostly empty space.
2. The answer will depend on the scale used by the students. If the scale is 1.98 m /AU, then the distance the star would be placed away from the Sun would be

   $$1.98 \text{ m}/\text{AU} \times 274{,}332 \text{ AU} = 543{,}178 \text{ m}.$$
3. Answers will vary with students. One disadvantage of the model in this activity is not being able to construct a size model on the same scale as the distance model. One advantage is the ability to represent the distances to the planets in a space that allows students to appreciate the emptiness of the Solar System.
4. Answers will vary with students, but the learning will come in thinking about the relative distances within the Galaxy compared to distances within the Solar System. The diameter of the Milky Way is estimated at 300,000 parsecs. One parsec is 3,260 ly. One light year is 63,000 AU. A visible model of these dimensions is nearly impossible to scale.

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A TOILET PAPER SOLAR SYSTEM SCALE MODEL

ACTIVITY D-6

GRADE LEVEL: 6-10

Source: Reprinted by permission from *Project Pulsar*, St. Louis Science Center, 5050 Oakland Avenue, St. Louis MO 63110. Publication is no longer in print.

What's This Activity About?

This is a wonderfully simple activity to demonstrate to students at all grade levels just how big space really is. Students enjoy the chance to be outside the classroom, and to bring in common objects to represent the sizes of planets. This activity is an excellent introduction to the study of astronomy in general, and the solar system in particular. It has a strong cooperative learning component.

What Will Students Do?

Using toilet paper squares as a standard measuring unit of 1 million or 10 million miles, students create a scale model of our solar system. The activity can be used to demonstrate the distances between planets for earlier grades, and is easily extended to upper grades by including the relative sizes of planets as well as their spacing, and even the time for light to travel between the planets. Let the students bring in objects from home to represent the planets.

Tips and Suggestions

- Allow at least one to two hours to map the entire solar system, and expect that some students may become distracted while outside. Also note that if you use 1 square per million miles, about 1/4 mile is required to include the Sun-Pluto distance. You will need eight 500-sheet rolls of toilet paper just to get to Pluto. Put a light near the Sun to make it easier to spot from far off.
- Consider starting the activity by getting students to predict where planets would be on their school grounds, based on the relative size of the Sun. (If the scale is 1 square of toilet paper per million miles, the 864,000-mile wide Sun would be a ball a little smaller than one square of toilet paper.) Follow up with activities on math (graphing distances and light travel time), writing (describing the feeling of "space" when standing on Pluto looking back at the grapefruit).
- Using toilet paper outside on a breezy day can be a problem. In this case, have students pace off the distances and mark them with chalk.
- See Activity D-5 for more ideas and extensions.

What Will Students Learn?

Concepts

The relative spacing of the planets and their sizes

Inquiry Skills

Modeling
Measuring
Ordering

Big Ideas

Models and Simulations
Scale

A TOILET PAPER SOLAR SYSTEM SCALE MODEL

MATERIALS NEEDED:

Index cards, 20 rolls of 500 sheet toilet paper.

THE ACTIVITY:

First be sure that your students undertand the concept of scale models. Ask the class why it is necessary to put things on a scale when discussing distance and size in astronomy. In this model, toilet paper represents an imaginary celestial yardstick, with each square of toilet paper representing 1 million (1,000,000) miles.

The table on the next page gives the average (approximate) distances of the planets from the Sun. PLEASE NOTE: The number of squares of T.P. listed by each planet is the distance from the Sun, *not* the distance from the preceding planet. The table also lists roughly how big each planet would be at this scale.

Write the names of the planets and the Sun on index cards and place small cut out circles representing the size of each planet on each card. Have groups of students count out squares of T.P. needed to reach each planet. Select a student from each group to represent each planet, and as the model is created, have them stand at the appropriate planet location with their index card.

In your school, there may not be enough open space (or enough toilet paper) to do the activity this way. In that case, you can change the scale to one square T.P. representing 10 million miles, cutting the distances (and squares of toilet paper needed) by a factor of ten. Then Pluto is only 37 meters from the Sun. (Note that with this scale, the planet diameters would also be 10 times smaller and very hard to see!)

This activity comes from Project Pulsar, at the St. Louis Science Center. It was originally developed by the late Gerald L. Mallon, Planetarium Director in the Methacton School District of Fairview Village, Pennsylvania, in 1979 and adapted from The Astronomy of One Constellation, *Kendall/Hunt Publishing Company, Dubuque, Iowa, 1976.*

Planet	Distance From Sun	Distance Needed	Planet Diameter
Mercury	36 sheets of TP	3.6 meters	hole made by small staple
Venus	57	5.7 meters	not quite the thickness of a paper clip
Earth	93	9.3 meters	thickness of a paper clip
Mars	141	14.1 meters	1/2 the thickness of a paper clip
Jupiter	483	48.3 meters	slightly larger than the thickness of a pencil
Saturn	886	88.6 meters (one football field)	thickness of a pencil
Uranus	1,783	178.3 meters (two football fields)	size of lace hole in sneaker
Neptune	2,793	279.3 meters (three football fields)	size of a lace hole in a sneaker
Pluto	3,675	367.5 meters (four football fields)	thickness of a small staple

THE THOUSAND-YARD MODEL (OR THE EARTH AS A PEPPERCORN)

ACTIVITY D-7

GRADE LEVEL: ALL

Source: By Guy Ottewell. Copyright ©1989 by Guy Ottewell, Astronomical Workshop, Furman University, Greenville, SC 29613.

What's This Activity About?

On the surface, this activity is very similar to "Toilet Paper Solar System Scale Model," and also to "Solar System Scale." The Thousand-Yard Model is both a participatory activity and a teacher-led tour. What really sets it apart is Ottewell's wonderful narrative and encouragement for relating more about the planets and their unique characteristics while the tour proceeds. This is an outstanding activity for teachers new to astronomy. Depending on the facts included, this tour can be done for any grade level.

What Will Students Do?

Using mostly common objects (pinheads, foods, and balls of various sizes from BBs to eight-inches across), students help to create a distance and scale model. The resulting tour of the solar system is based on pacing off the approximate distances to the planets.

Tips and Suggestions

- The actual distances used here are not as precise as those in the other two activities mentioned above, since the lengths of students' and teachers' paces will vary.
- The activity is useful as an introduction to the planets, relating their position about the Sun to some of their characteristics like temperature, size, number of moons, and composition.
- For earlier grades, the spacing of planets will probably be the most dominant concept. Consider using larger color pictures of the planets in addition to the scaled objects.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Planetary Size and Spacing	Comparing	Scale
	Describing	Structure
	Measuring	Models and Simulations
	Inferring	

Can you picture the dimensions of the solar system? Probably not, for they are of an order so amazing that it is difficult either to realize or to show them.

You may have seen a diagram of the Sun and planets, in a book. Or you may have seen a revolving model of the kind called an orrery (because the first was built for an Earl of Orrery in 1715). But even the largest of such models—such as those that cover the ceilings of the Hayden Planetarium in New York and the Morehead Planetarium at Chapel Hill—are far too small. They omit the three outermost planets, yet still cannot show the remaining ones far enough apart.

The fact is that the planets are mighty small and the distances between them are almost ridiculously large. To make any representation whose scale is true for the planets' sizes ***and*** distances, we must go outdoors.

The following exercise could be called a Model, a Walk, or a Happening. I have done it more than twenty times with groups of varied ages (once we were televised) or with a single friend; and others, such as elementary-school teachers, have carried it out with these instructions. Since it is simple, it may seem suitable for children only. It can, indeed, be done with children down to the age of seven. Yet it can also be done with a class consisting of professors of astronomy. It will not waste their time. They will discover that what they thought they ***knew***, they now ***apprehend***. To take another extreme, the most uncontrollable high-school students or the most blasé college students unfailingly switch on their full attention after the first few paces of the excursion.

There is one other party that may profitably take the planet-walk, and that is yourself, alone. Reading the following description is no substitute: you must go out and take the steps and look at the distances, if the awe is to set in.

First, collect the objects you need. They are:

Sun—any ball of diameter 8 inches.
Mercury—a pinhead, diameter .03 inch.
Venus—a peppercorn, diameter .08 inch.
Earth—a second peppercorn.
Mars—a second pinhead.
Jupiter—a chestnut, pecan, or gooseberry, diameter .9 inch.
Saturn—a filbert (hazelnut) or acorn, diameter .7 inch.
Uranus—a peanut or coffeebean, diameter .3 inch.
Neptune—a second peanut or coffeebean.
Pluto—a third pinhead (smaller, if possible, since Pluto is the smallest planet).

You may suspect it is easier to search out pebbles of the right sizes. But the advantage of distinct objects such as peanuts is that their rough sizes are remembered along with them. It does not matter if the peanut is not exactly .3 inch long; nor that it is not spherical.

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A standard bowling ball happens to be just 8 inches wide, and makes a nice massive Sun, so I couldn't resist putting it in the picture. But it may not be easy to find and certainly isn't easy to carry around. There are plenty of inflatable balls which are near enough in size.

The three pins must be stuck through pieces of card, otherwise their heads will be virtually invisible. If you like, you can fasten the other planets onto labeled cards too.

Begin by spilling the objects out on a table and setting them in a row. Here is the moment to remind everyone of the number of the planets—9—and their order—MVEMJSUNP. (This *mvemonic* could be made slightly more pronounceable by inserting the asteroids in their place between Mars and Jupiter: MVEMAJSUNP.)

The first astonishment is the contrast between the great round looming Sun and the tiny planets. (And note a proof of the difference between reading and seeing: if it were not for the picture, the figures such as "8 inches" and ".08 inch" would create little impression.) Look at the second peppercorn—our "huge" Earth—up beside the truly huge curve of the Sun.

Having set out the objects with which the model is to be made, the next thing is to ask: "How much space do we need to make it?"

Children may think that the table-top will suffice, or a fraction of it, or merely moving the objects apart a little. Adults think in terms of the room, or a fraction of the room, or perhaps the corridor outside.

To arrive at the answer, we have to introduce scale. *This peppercorn is the Earth we live on.*

The Earth is eight thousand miles wide! The peppercorn is eight hundredths of an inch wide. What about the Sun? It is eight *hundred* thousand miles wide. The ball representing it is eight inches wide. So, one inch in the model represents a hundred thousand miles in reality.

This means that one yard (36 inches) represents 3,600,000 miles. Take a pace: this distance across the floor is an enormous space-journey called "three million six hundred thousand miles."

Now, what is the distance between the Earth and the Sun? It is 93 million miles. In the model, this will be 26 yards.

This still may not mean much till you get one of the class to start at the side of the room and take 26 paces. He comes up against the opposite wall at about 15!

Clearly, it will be necessary to go outside.

Hand the Sun and the planets to members of the class, making sure that each knows the name of the object he or she is carrying, so as to be able to produce it when called upon.

You will have found in advance a spot from which you can walk a thousand yards in something like a straight line. This may not be easy. Straightness of the course is not essential; nor do you have to be able to see one end of it from the other. You may have to "fold" it back on itself. Ideally, it should be a unit that will make a good story afterwards, like "All the way from the flagpole to the Japanese garden!"

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Put the Sun ball down, and march away as follows. (After the first few planets, you will want to appoint someone else to do the actual pacing—call this person the "Spacecraft" or "Pacecraft"—so that you are free to talk.)

- 10 paces. Call out "Mercury, where are you?" and have the Mercury-bearer put down his card and pinhead, weighting them with a pebble if necessary.
- Another 9 paces. Venus puts down her peppercorn.
- Another 7 paces. Earth.

Already the thing seems beyond belief. Mercury is supposed to be so close to the Sun that it is merely a scorched rock, and we never see it except in the Sun's glare at dawn or dusk—yet here it is, utterly lost in space! As for the Earth, who can believe that the Sun could warm us if we are that far from it?

The correctness of the scale can be proved to skeptics (of a certain maturity) on the spot. The apparent size of the Sun ball, 26 paces away, is now the same as that of the real Sun—half a degree of arc, or half the width of your little finger held at arm's length. (If both the size of an object and its distance have been scaled down by the same factor, then the angle it subtends must remain the same.)

- Another 14 paces. Mars.

Now come the gasps, at the first substantially larger leap:

- Another 95 paces to Jupiter.

Here is the "giant planet"—but it is a chestnut, more than a city block from its nearest neighbor in space!

From now on, amazement itself cannot keep pace, as the intervals grow extravagantly:

- Another 112 paces. Saturn.
- Another 249 paces. Uranus.
- Another 281 paces. Neptune.
- Another 242 paces. Pluto.

You have marched more than half a mile. (The distance in the model adds up to 1,019 paces. A mile is 1,760 yards.)

To do this, to look back toward the Sun ball which is no longer visible even in binoculars, and to look down at the pinhead Pluto, is to feel the terrifying wonder of space.

That is the outline of the Thousand-Yard Model. But be warned that if you do it once you may be asked to do it again. Children are fascinated by it enough to recount it to other children; they write "stories" which get printed in the school paper; teachers from other schools call you up and ask you to demonstrate it.

So the outline can bear variation and elaboration. There are different things you can remark on during the pacings from one planet to the next, and there are extra pieces of information that can easily be grafted on. These lead forward, in fact, to the wider reaches of the universe, and make the planet walk a convenient introduction to a course in astronomy. But omit them if you are dealing with children young enough to be confused, or if you yourself would prefer to avoid mental vertigo.

I recommend that you stop reading at this point, carry out the walk once, and then read the further notes.

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Establishing the scale

While you are talking and introducing the idea of the model, it may be helpful (depending on the age of the audience) to build up on a blackboard something like this:

	real		*in model*
Earth's width	8,000 miles		8/100 inch
Sun's width	800,000 miles		8 inches
therefore scale is	100,000 miles	⇨	1 inch
therefore	3,600,000 miles	⇨	36 inches or 1 yard
and Sun-Earth distance	93,000,000 miles	⇨	26 yards

Follow-up

Having come to the end of the walk, you may turn your class around and retrace your steps. Re-counting the numbers gives a second chance to learn them, and looking for the little objects re-emphasizes how lost they are in space.

It works well, in this sense: everyone pays attention to the last few counts—"240 . . . 241 . . . 242"—wondering whether Neptune will come into view. But it does not work well if the peanut cannot be found, which is all too likely; so you should, if you plan to do this, place the objects on cards, or set markers beside them (large stones, or flags such as the pennants used on bicycles).

Also, the Sun ball perhaps cannot be left by itself at the beginning of the walk—it might be carried off by a covetous person if not by the wind—so send someone back for it when the walk has progressed as far as Mars.

(I once, having no eight-inch ball, made a colored paper icosahedron, and had to give chase from afar when I saw someone appropriating it. On the return from another walk, I met a man holding his mouth while his worried companion said "Did you bite it?"—incredibly, he had picked up one of the peppercorns! The other edible planets are, of course, prey for passers-by. Hazards like these may be regarded as our model's counterparts of such cosmic menaces as supernovae and black holes.)

On each card, the child who recovers it may write briefly the place where it was—"At 5th Street," "At John Cabonie's house" . . . Then, back in the classroom, the objects are kept in a row on a shelf, as a reminder of the walk. Or they may be hung on strings from a rafter.

Since pecans, pinheads, peanuts and especially peppercorns cannot always be readily found when another demonstration is called for, I keep at least one planetary system on hand, in one of the small canisters in which 35-millimeter film is sold.

Looking at the real things

Anyone you take on this planet-walk may finish it with a desire to set eyes on the planets themselves. So it is best to be able to do it at a date when you can say: "Look up *there* after dark and you will see [Jupiter, for instance]."

Thus on the first nights of 1990, when darkness falls, Jupiter will be the brightest "star" high in the east of the sky, and Venus will be the brightest one setting in the west.

For any other specific times, consult the *Astronomical Calendar*, the magazines *Sky & Telescope* or *Astronomy*, or a local college science department, planetarium, or amateur astronomer.

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EXTRATERRESTRIAL EXCURSIONS

ACTIVITY D-8

GRADE LEVEL: 4-7

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What's This Activity About?

This is a great exercise on the scale of the solar system that develops mathematical skills in fractions, remainders, rounding, and (subtly) conversion of units. Astronomy offers a wonderful opportunity for students to apply mathematics to real problems, and these AIMS activities are outstanding examples of directed math exploration.

What Will Students Do?

Students compute travel times to the Moon and planets, and determine their age on arrival (based on a current rocket's speed of 40,000 km per hour).

Tips and Suggestions

- This activity works very well as a follow-up to the scale models, as students will have a much better appreciation of the vast physical spaces between the planets which match their numerical answers.
- Students in later grades can also determine how fast they need to travel to reduce the overall travel time to days (or hours!), and they could even use the speed of light (300,000 km/second) to determine how long electromagnetic energy—including sunlight or radio signals from Earth to spacecraft—would take to span the distances in our solar system. You can also easily include the concepts of fuel, "gas mileage," and energy use, to extend the activity even further.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Speed	Calculating	Scale
Traveling through the solar system	Imagining	

EXTRATERRESTRIAL EXCURSIONS

Topic Area
Planets

Introductory Statement
Travel time to the moon and the planets will be computed so that students can determine their ages after making imaginery excursions.

Math
Using computation
Rounding
Estimating
Problem solving
Using rational numbers
  decimals
Using calculators

Science
Astronomy
  planets

Math/Science Processes
Recording data
Interpreting data
Predicting and inferring
Making and testing hypotheses
Applying and generalizing

Material
Calculators

Key Question
Traveling at a speed of 40,000 kilometers per hour, how old would you be upon your arrival at the moon and each planet?

Background Information

The distance to the moon and each planet (in kilometers) is listed on the student worksheet. (If a teacher prefers, these distances can be researched by the students.) The speed of 40,000 kilometers per hour was determined by the speed of space travel we would be capable of today. Obviously there would be more to interplanetary travel than how long it would take, and students may bring up all those problems.

Since the answers to the first three computations should be rounded, rounding strategies should be taught prior to this activity. The last computation (converting months to years) should be done without a calculator, as the remainder will tell students the number of months. This serves as a good example of a situation in which computing with a calculator won't work. The final activity sheet, *Special Delivery*, gives students the opportunity to use the information in a problem-solving format.

Management
1. Time for this activity will vary depending on the students' math abilities and whether or not calculators are used.
2. Students can work in pairs or groups to compute travel time and then individually to compute their age on arrival.
3. The formulas should be discussed before students do the worksheet. The formula *rate x time = distance* is an important one which students can use in a variety of situations. We use it as a division formula solving for time.
4. Teaching the process of crossing through an equal number of zeroes before dividing is very helpful. If students are dividing without calculators, this means they only need to divide by 4.
5. When doing *Special Delivery*, students have to be reminded that a visit to any planet is not complete until they return to earth.

Procedure
1. On *Extraterrestrial Excursions*, students will record their ages in years and months.
2. Students will predict how long it will take to travel to the moon and each of the planets; then they will record their predicted ages on arrival.
3. Students will use the formulas to compute travel time to the moon and each planet.
   - Compute hours of travel time by dividing the distance from Earth by the speed of 40,000 kilometers per hour. Round to the nearest hour.
   - Compute the days traveled by dividing the hours by 24 and round to the nearest day.
   - Compute travel time in months by dividing days by 30 and rounding to the nearest month.
   - Compute years traveled by dividing months by 12 without using a calculator. The remainder is used to record the number of years and months.
4. By adding that amount of time to their ages, students will arrive at their actual ages at the time of arrival.
5. Students record their actual arrival ages in the last column on the worksheet.
6. Students use the information about travel time to answer the questions on *Special Delivery*.
7. Students create their own mystery trips for their classmates to answer.

Discussion
1. How did your predictions compare to the actual age you would be?
2. Were you surprised by how long or short a time it would take for interplanetary travel?

Extensions
1. Have students compute how long it would take them to travel to a given planet and return.
2. Ask students to compute the arrival ages for other family members.
3. Students can list supplies needed for a lengthy voyage.
4. Have students write an imaginary journal of their voyage.

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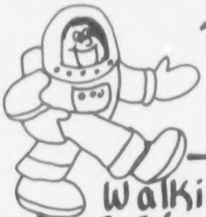
Travel Time

The great distances in space are sometimes difficult to comprehend. If we look at the time it would take to travel to the moon and the planets by walking, by car, or by jet plane, we can begin to understand what a great undertaking interplanetary travel would be.

TIME IN YEARS FROM EARTH



Planetary Body	Walking 2.5/mph 3.6/Kmph	Car 55mph 80 Kmph	Jet 990 mph 1436 Km ph
Moon	11	.6	.03
Mercury	2588	133	7
Venus	1175	61	3
Mars	2222	113	6
Jupiter	17,843	909	46
Saturn	36,421	1848	92
Uranus	76,894	3935	194
Neptune	123,579	6289	313
Pluto	162,622	8378	410

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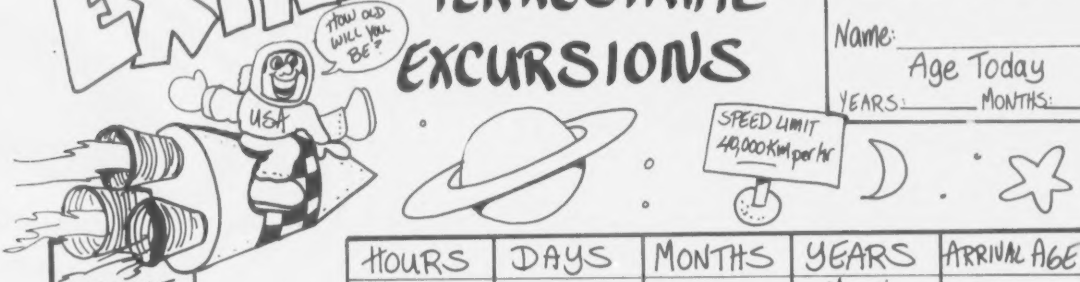
EXTRA TERRESTRIAL EXCURSIONS

SPACE VOYAGER
Name: ____________
Age Today
YEARS: ______ MONTHS: ______


How old will you be?
USA
SPEED LIMIT 40,000 Km per hr

AVERAGE DISTANCE FROM EARTH		HOURS	DAYS	MONTHS	YEARS		ARRIVAL AGE	
		Distance / 40,000	Hours / 24	Days / 30	Month / 12		Years + your Age	
		(to nearest hour)	(to nearest day)	(to nearest month)	Years	Months	Years	Months
384,000 Km	Moon							
92,000,000 Km	Mercury							
41,000,000 Km	Venus							
78,000,000 Km	Mars							
629,000,000 Km	Jupiter							
1,227,000,000 Km	Saturn							
2,721,000,000 Km	Uranus							
4,347,000,000	Neptune							
5,750,000,000	Pluto							

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EXTRA TERRESTRIAL EXCURSIONS

SPACE VOYAGER
USA
SOLAR SYSTEM DELIVERY SERVICE

SPECIAL DELIVERY

Imagine that you work for the Solar Systems Delivery Service. You need to determine the time necessary to make certain deliveries and return to Earth. The planets are not lined up in a straight line in their orbits around the sun. You must always return to Earth for refueling between planets.

REMEMBER: YOUR JOURNEY IS NOT OVER UNTIL YOU RETURN TO EARTH!
PIZZA

1. Deliver communication systems to Mercury and Jupiter.

TRAVEL TIME: ___________

2. Deliver pizza to Venus and Mars.

TRAVEL TIME: ___________

3. You travel to one outer and one inner planet and back home again. Your journey takes you about 7 years, 6 months. To which planets did you travel?

Planets: ___________ ___________

4. Starting at Neptune, you travel home to Earth and then deliver letters to Mars.

TRAVEL TIME: ___________

5. Design a "Mystery" trip to two of the planets. Remember to always stop at the Earth between planets. How long would your mystery trip take?

TRAVEL TIME: ___________

Exchange "Mystery" trips with another student and solve.

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TIME TRAVELER

ACTIVITY D-9

GRADE LEVEL: 6-9

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What's This Activity About?

"Time Traveler" introduces the concept of "light-years" as a standard astronomical distance unit. Like "Extraterrestrial Excursions," this activity can be used as a mathematical follow-up to a solar system scale model, and as an introduction to the stars or constellations.

What Will Students Do?

Students walk heel-to-toe for one minute, measure the distance they walked, and use that as an analogy for the distance light travels in a specified time. Students find the average of several measurements to create a standard unit called a "student minute."

Tips and Suggestions

- Have students measure or estimate the distances between planets of one of the scale models of the solar system to apply the concept of a "student minute."
- Have students take the part of planets and walk "orbiting" the sun, with the more distant students representing outer planets walking slightly slower. Ask an appointed messenger to travel from one planet to another, while all the planets are moving. Students can time their travel, and investigate what directions they must head to rendezvous in space in the least amount of time.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Distances as measured in units of time	Measuring	Scale
Light-years	Calculating	Models and Simulations
	Inferring	

Time Traveler

Background

Distances in astronomy are often very difficult to comprehend because they are so large. For example, the distance from the star Sirius to Earth is 84,320 trillion km. This distance is too large for most people to imagine or understand. There are ways, however, to make such large numbers more manageable. For example, it is much easier to understand and work with 15 years than with 5,475 days, even though they both represent the same amount of time. A "year" is just a much larger unit than a "day." The same type of thing can be done with distances using a measurement known as a **light year**.

A light year (abbreviated "ly") is a measurement of distance even though it involves a time unit, the year. A light year is defined as the distance that light will travel in one year. The speed of light is 300,000 km/s. To calculate how far light travels in one year, first calculate how many seconds there are in a year:

$$60 \text{ s/min} \times 60 \text{ min/hr} \times 24 \text{ hr/d} \times 365 \text{ d/yr} = 31,536,000 \text{ s/yr}$$

So in one year, light will travel

$$\begin{aligned} &31,536,000 \text{ s} \times 300,000 \text{ km/s} \\ &= 9,461 \text{ trillion } (9,461,00,000,000,000) \text{ km} \end{aligned}$$

This is the same as traveling around the world 118 million times.

The light year can make distances easier to understand in the same way that a year makes a large number of days more understandable. Returning to our example above, the distance to the star Sirius from Earth is 84,320 trillion km. But this distance is only 9 ly, a much more manageable number.

The light year is also important because it tells us about the time lag involved in communicating over the large distances involved in astronomy. If we sent a television or radio signal (both of which travel at the speed of light) to Sirius, it would be nine years before it arrived there. In the same way, if Sirius were to stop shining right now, we would not find out about it for nine more years, when the last light the star produced finally reached Earth. How old would you be then?

Procedure

1. Find a long distance that you can use either inside or outside the school. This could be a long hallway, the cafeteria, a

Objective

The objective of this activity is to develop an understanding of the concept of a unit known as the "light year."

Materials

For each group of students:

- ◊ watch with second hand or a stop watch
- ◊ metric tape measure (30 meters or more works best)
- ◊ calculator (helpful but not essential)

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parking lot, or a football field. You won't need a distance longer than a football field.

2. Starting at one end of the space you have chosen, walk heel-to-toe for exactly one minute. Mark where you stop.
3. Using the tape measure, measure how far you walked to the nearest meter. Record this distance in the Data Table.
4. Repeat steps 2 and 3 three more times.
5. Calculate the average of the four measurements and record it in the Data Table.

DATA TABLE

	Distance walked	Average distance walked
Trial 1		
Trial 2		
Trial 3		
Trial 4		

6. The average you calculated is the distance you can walk heel-to-toe in one minute. We will call this distance a "student minute."

Questions and Conclusions

1. Are all the student minutes the same? How are they similar?
2. How are student minutes similar to a light year? How are they dissimilar?
3. How many meters are in 3 student minutes?
4. How many of your student minutes are there in 5,000 m?
5. Listening to the radio one morning at 6:30, you hear that school has been cancelled because of damage done in some parts of town by a windstorm. You start to climb back in bed and sleep the day away, but then you remember that your best friend lives in a part of town which was heavily damaged and has no telephone or electricity. Your friend leaves for school every morning at 7:00 and lives 900 m away from you. The only way you can get the news to your friend is to go to your friend's house and deliver the message. If you are only allowed to walk heel-to-toe, can you make it to the house in time based on your own student minute? Explain.

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Time Traveler

What Is Happening?

Distances in astronomy are extremely hard for adults to comprehend, let alone middle or high school students. The units typically used for large measurements on Earth (the kilometer or mile) are too small to be of much help when measuring the distance to stars or other galaxies. For this reason, a unit known as the light year was developed. A light year is defined as the distance that light can travel in one year. Traveling at 300,000 km/s, light travels almost 9,461 trillion km in one year.

The light year is a difficult unit for students to understand. The problem lies in the terminology. A time unit, the "year," is being used to measure distance. This is not at all unfamiliar to students, however. It is very common today to talk about distance in terms of time. Students often do not talk about how many miles it is to a friend's house but how many minutes or hours it takes to get there. A comparison of the time-distance to a friend's house when walking, bicycling, or riding in a car can be a useful illustration of the concept that the time-distance unit depends on the speed of the carrier. Since light is the fastest (and most constant) possible carrier, it is the most useful for establishing the scale of huge astronomical distances.

The light year has another important property that is discussed in more detail in Activity 4, "Hello Out There!" The distance in light years that an object is from Earth is the amount of time in years that light from this object would take to reach Earth. For example, if a star is 12 ly from Earth, light from the star takes 12 years to reach us. Likewise, any light from Earth takes 12 years to reach the star.

This activity is designed to help students understand the light year by creating for themselves a unit which is similar, one that uses time to measure distance. It is important that students understand the nature of the unit. Creating their own unit should aid in this understanding. An important distinction, however, needs to be made between the "student minute" and the light year. The student minute may vary depending on how fast the student walks. The light year does not vary. It is a constant because the speed of light is a constant.

Materials

For each group of students:

- ◊ watch with second hand or a stop watch
- ◊ metric tape measure (30 meters or more works best)
- ◊ calculator (helpful but not essential)

Vocabulary

Light year: A unit of measurement equal to the distance light travels in one year (9,461 trillion km or 9,461,000,000,000,000 km).

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Important Points for Students to Understand

◊ Distances in astronomy are too large to work with easily when expressed in units such as kilometers. Using a larger unit makes these numbers easier to manage.
◊ The "light year" is a measurement of distance even though it involves a time unit.
◊ It is very common to express distances in terms of time.
◊ Light has a finite speed. It takes time for light to travel over any distance.

Time Management

Depending on the availability of watches and tape measures, this activity should take one class period or less.

Preparation

You should determine in advance what area the students will use for this activity. If an outdoor site is to be used, be sure the conditions are such that the students can remain outside comfortably for an extended period of time.

Rather than having the students measure each time they walk, it may be possible to use a lined football field. Alternatively, the teacher may mark off the distance. This can be done simply with a tape measure and marking paint.

For additional background, see Reading 2, "What is a Light Year?" and Reading 3, "Hubble Space Telescope."

Suggestions for Further Study

It is helpful for students to gain experience with conversions. One way to accomplish this is to have them convert some distances they are familiar with to their own student minute. They may also find it interesting to convert the distance to some stars, which are recorded in light years, into kilometers.

Students can also determine their student minute doing other things besides walking heel-to-toe. They may walk normally or run.

Suggestions for Interdisciplinary Reading and Study

The light year is simply a unit that makes vast distances easier to work with, as explained in the Background section. There are

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examples of units like this in students' everyday lives. For example, a "dozen" is just another way of representing twelve of something. It is easier to talk about ten dozen eggs than 120 of them. An hour is just an easier way of representing 60 minutes. Ask students to think of other units like this in their own experience. In a writing activity, they could invent their own unit, name it, describe it, and explain how it would be used. For example, what is a "mom minute," as in "Yes, Mom. I'll be there in a minute!"

The concept of distance in the Solar System is sometimes expressed in literature. One example is the poem at the begining of this activity, "A Distant Sun," by Lydia Ferguson.

Answers to Questions for Students

1. No, all the student minutes should not be the same.
2. The two are similar in that they both involve a time unit in a distance measurement. Both involve measuring how far something can travel in a given amount of time. The major dissimilarity is in the size of the respective units. But also, the light year is a constant because the speed of light is constant. The student minutes will vary because of the variation in how fast different individuals walk as well as variation in how fast one person walks at different times.
3. Again, this answer will depend on the student minute. For example, if a student minute is calculated to be 30 m, then the answer is:

   (3 student minutes) × (30 m/student minute) = 90 m.
4. This answer will vary depending on each different student minute. A student minute of 30 m is reasonable to assume. In this case, the answer would be:

   5,000 m ÷ 30 m/student minute = 166.7 student minutes.
5. Assuming 30 m for the student minute, it would take the student 900 m/30 m = 30 student minutes to reach the friend's house. Therefore, the student should get there just as the friend is leaving.

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I. Stellarum fixarum sphera immobilis.
II. Saturnus anno XXX revolvitur.
III. Iovis XII annorum revolutio.
IIII. Martis bima revolutio.
V. Telluris cum orbe lunari annua revolutio.
Sol.

RESOURCES FOR EXPLORING OUR SOLAR SYSTEM IN GENERAL

by Andrew Fraknoi
Astronomical Society of the Pacific
390 Ashton Avenue
San Francisco, CA 94112

NOTE: Books or articles marked with a • are especially useful for those just beginning their exploration of the solar system.

(See also the resource list for each planet)

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

- • Morrison, D. *Exploring Planetary Worlds.* 1993, Scientific American Library/W. H. Freeman. The best up-to-date popular-level survey of the solar system, by an astronomer.

- • Henbest, N. *The Planets: A Guided Tour.* 1993, Viking Penguin. A colorful introduction by a British science writer, with many illustrations.

- • Sagan, C. *Pale Blue Dot.* 1994, Random House. Eloquent essays celebrating the exploration of the planets, the uniqueness of the Earth, and our future in space. See also his 1980 book *Cosmos,* which has wonderful introductions to some of the planets.

Preiss, B., ed. *The Planets.* 1985, Bantam. A collection of articles about each planet by astronomers, and science fiction stories based on those articles by science fiction writers. Many are useful for modeling how to do an invent an alien activity.

- • Miller, R. & Hartmann, W. *The Grand Tour,* 2nd ed. 1993, Workman. Lavishly illustrated "travel guide" for the solar system, by an artist and an astronomer.

Frazier, K. *The Solar System.* 1985, Time Life Books. Nice primer by a science journalist.

Kelch, J. *Small Worlds: 60 Moons of the Solar System.* 1990, Julian Messner. Basic survey of the many moons our spacecraft have revealed. Can be used by older students.

Schaaf, F. *Seeing the Solar System.* 1991, Wiley. Observing activities for small telescopes.

Elliot, J. & Kerr, R. *Rings: Discoveries from Galileo to Voyager.* 1985, MIT Press. Nice history of how we learned about the 4 planetary rings in the solar system, by the scientist who discovered the rings of Uranus.

Morrison, D. & Owen, T. *The Planetary System.* 1988, Addison Wesley. The definitive college textbook in this field, very well written and clear. New edition coming soon.

Chapman, C. & Morrison, D. *Cosmic Catastrophes.* 1989, Plenum. Excellent introduction to collisions and catastrophes in the solar system, including what may have killed the dinosaurs.

Sheehan, W. *Worlds in the Sky.* 1992, U. of Arizona Press. A nice introduction to the history of planetary astronomy.

For those with a more technical background, the definitive survey of the solar system is a collection entitled *The New Solar System,* 3rd ed., edited by J. Kelly Beatty, et al. (1990, Cambridge University Press and Sky Publishing.)

- • Gore, R. "Between Fire and Ice: The Planets" in *National Geographic,* Jan. 1985, p. 4.

Barnes-Svarney, P. "The Chronology of Planetary Bombardments" in *Astronomy*, July 1988, p. 21. How collisions shaped the early history of the solar system.

Whitmire, D. & Reynolds, R. "The Fiery Fate of the Solar System" in *Astronomy*, Apr. 1990, p. 20. How the evolution of the Sun will affect the planets.

Lanzerotti, L. "The Planets' Magnetic Environments" in *Sky & Telescope*, Feb. 1989, p. 149.

Ciaccio, E. "Atmospheres" in *Astronomy*, May 1984, p. 6.

Readings on Observing or Photographing the Planets

Coco, M. "How to Make a Planetary Portrait" in *Astronomy*, July 1990, p. 62.

Dobbins, T., et al. *Introduction to Observing and Photographing the Solar System*. 1988, Willmann-Bell. An introduction to techniques for serious observers, full of good detail.

O'Meara, S. "Observing Planets: A Lasting Legacy" in *Sky & Telescope*, Nov. 1988, p. 474.

Parker, D. & Dobbins, T. "The Art of Planetary Observing" in *Sky & Telescope*, Oct. 1987, p. 370; Dec. 1987, p. 603.

Sessions, L. "Observing the Planets in the Daytime" in *Astronomy*, Jan. 1981, p. 40.

SELECTED READINGS FOR STUDENTS

Grades 4-6

Asimov, I. & Walz-Chojnacki, G. *Our Planetary System*. 1994, Gareth Stevens.

Barnes-Svarney, P. *Traveler's Guide to the Solar System*. 1993, Sterling. Very nice overview of the planets and moons.

Brenner, B. & Miller, R. *Planetarium*. 1993, Bantam. A kid's tour of an imaginary museum showing the planets and more.

Lauber, P. *Journey to the Planets*, 4th ed. 1993, Crown.

Couper, H. & Henbest, N. *The Planets*. 1987, Franklin Watts.

Ardley, N. *The Inner Planets and The Outer Planets*. 1987, 1988, Schoolhouse Press.

Estallela, R. *Planets and Satellites*. 1993, Barron's Educational.

Lambert, D. *The Solar System*. 1984, Bookwright Press.

Adler, D. *Hyperspace: Facts and Fun from All Over the Universe*. 1982, Viking. Despite its title, this book, full of cartoons and activities, is mostly about the solar system.

Carroll, M. "Oceans on Other Worlds" in *Odyssey*, 1993, issue 5, p. 4.

Dyer, A. "Weather That's Out of This World" in *Odyssey*, 1993, issue 3, p. 10.

Carroll, M. "Vocanoes on Other Worlds" in *Odyssey*, 1993, issue 1, p. 24.

Grades 7-9

Hatchett, C. *Discover Planetwatch*. 1993, Hyperion Books. A basic guide to the solar system with 17 observational projects for youngsters.

Davis, D. & Levasseur-Regourd, A. *Our Sun and the Inner Planets*. 1989, Facts on File.

Davis, D. & Yeomans, D. *Distant Planets*. 1989, Facts on File.

Taylor, G. *Vocanoes in the Solar System*. 1983, Dodd Mead. By a scientist.

SELECTED AUDIOVISUAL MATERIALS

The Planetary System (1988 slide set, Astronomical Society of the Pacific) A collection of the 100 most important recent images of the solar system, selected and with captions by astronomer David Morrison. Comes with extensive booklet of information and background on all the planets. (Also available on a set of Mac disks for displaying on a computer.) A teachers' version, with 25 slides, including several new ones not in the original set, is available under the title Teachers' Solar System Slide Set.

Worlds in Comparison, 3rd ed. (1992 slide set, Astronomical Society of the Pacific) 20 slides and an information booklet: each slide compares two or more worlds or features in the solar system, giving students a sense of scale.

The Planets (1992, 51-min video from BMG Video or the Astronomical Society of the Pacific) Superb tour of the solar system narrated by Patrick Stewart.

The New Solar System (1994, 60-min video from Finley-Holiday Films) Tour of the solar system with up-to-date visuals.

On Robot Wings (1992 30-min video from Finley-Holiday Films) An excellent compilation of short computer animated flyover's of Earth and other planets.

Planetscapes and Voyager Gallery (1989 videodiscs, Optical Data/Astronomical Society of the Pacific) 12-inch laserdiscs with a wide variety of planetary images.

Cosmos (1980 video, Turner Home Video/ Astronomical Society of the Pacific) Several episodes of this award-winning and eloquent public TV series deal with the planets.

Tales from Other Worlds (1986 video, Annenberg/Astronomical Society of the Pacific) An episode of the Planet Earth public television series, touring the planets and discussing the asteroid that may have killed the dinosaurs.

Dance of the Planets (ARC Software) For IBM compatibles, this wonderful software simulates and displays many different types of solar system phenomena, showing the planets and satellites up close, from above the system's plane, or in the Earth's night sky.

E

COMETS AND METEORS

E COMETS AND METEORS

ACTIVITIES INCLUDED IN COMETS AND METEORS

ACTIVITY	ESTIMATED GRADE LEVEL											
Grades	1	2	3	4	5	6	7	8	9	10	11	12
E-1. Experimenting with Craters Students observe the characteristics of craters formed by dropping an object into a pan of flour.				■	■	■	■	■	■	□	□	□
E-2. Make a Model Comet Students use cotton balls and string to create a scale model of a typical comet's coma and tail.				■	■	■	□	□				
E-3. Making a Comet in the Classroom You or your students create a scientifically accurate model of a comet for the students to observe.				■	■	■	■	■	■	□	□	□
E-4. Make a Comet Motion Flip Book Students create a "flip book" to simulate the motion of Halley's Comet around the Sun and the development of its tail.				■	■	■	□					

■ - Grade levels recommended by authors □ - Can be extended to these grade levels

About the Activities:

Comets and Meteors

Key Ideas in "Comets and Meteors"

- In contrast to the regular cycles of the Sun, Moon, and stars, comets and meteors demonstrate irregular and unexpected changes.
- All students should have an opportunity to see comets and meteors in the sky; so, if possible, arrange for an observing trip to the countryside.
- Scientists were slow to accept the idea that comets and meteors are actually visitors from space.
- Comets and meteors tell us about the early solar system and what happens to bodies in the space environment.
- The *Benchmarks* recommends that comets and meteors be introduced at the 6-8 grade levels, and that students not learn about them as separate phenomena, but as different aspects of space debris.

Not all of astronomy is as regular and cyclic as the daily turnings of the Sun and stars, or the monthly cycle of the Moon. The lovely and ever-changing tail of a comet and the surprising streak of a large meteor are two of the most spectacular irregularities in nature, and they should be a very important part of every schoolchild's astronomy curriculum.

As with all topics in astronomy, it is best if your students can see these objects in the sky. Be warned, however, that comets and meteors are not easy to observe. The pictures of comets that we see are usually taken with telescopes and long-exposure cameras, so the fuzzy smear of a typical naked-eye comet can be disappointing. And the annual meteor showers, most of which occur in August, are generally at their peak after midnight. Furthermore, both comets and meteors are faint phenomena, and can only be seen clearly and easily in the countryside, away from city lights. Nonetheless, if your newspaper announces that a naked-eye comet is expected in the coming weeks, or that the Earth is expected to pass through a swarm of space junk, causing a meteor shower at a certain date, it is well worth the effort to plan a star party out in the country, or to time a camping trip to view these celestial visitors.

Although modern astronomers accept the fact that both meteors and comets are "leftovers" from the formation of the solar system that have wandered through space until their visits to our planet, the idea was very slow to be accepted. Until Tycho Brahe measured the distance to a comet in the 16th century, many people thought that they were an atmospheric phenomenon. And it wasn't until the 19th century that astronomers came to believe that meteors were rocks from space that had burned up in the Earth's atmosphere. Now we know that comets and meteors are from space, and that study of these objects tells us about the early solar system.

The *Benchmarks for Science Literacy* recommends that comets and meteors be introduced as a major topic at the 6-8 grade levels, when students "add more detail to their picture of the universe, pay increasing attention to matters of scale, and back up their understanding with activities using a variety of astronomical tools." (*Benchmarks*, page 63.) Also quite important is the recommendation that students not learn about meteors, asteroids, and comets as separate phenomena, but as different aspects of space debris. In the following quote you will see that definitions are purposely left out, to better emphasize the overall concept: "By the end of eighth grade, students should know that...Large numbers of chunks of rock orbit the sun. Some of those that the Earth meets in its yearly orbit around the sun glow and disintegrate from friction as they plunge through the atmosphere—and sometimes impact the ground. Other chunks of rocks mixed with ice have long, off-center orbits that carry them close to the Sun where the Sun's radiation (of light and particles) boils off frozen material from their surfaces and pushes it into a long, illuminated tail." (*Benchmarks*, page 63.)

Without detracting from the emphasis on natural space debris as the unifying concept, we would like to offer a few definitions for use by teachers in reviewing instructional materials. **Meteoroids** are chunks of rock in space. When they enter the Earth's atmosphere and start to burn and glow from the friction they become visible as **meteors**. Meteor fragments that survive the fall are called meteorites. Very large chunks of rock in space, some as large as mountains, are called **asteroids**. Thousands of asteroids orbit between Mars and Jupiter, and a few have orbits that bring them into the vicinity of Earth.

Comets are different from asteroids in that they contain significant amounts of ice that vaporizes and glows when exposed to the light and charged particles that stream outwards from the Sun. Comets differ from meteors in that they are much larger and they do not have to enter the Earth's atmosphere to be visible. While a meteor streaks across the sky in a few seconds or less, comets are visible for weeks as they slowly move against the background stars, much like the planets.

The first activity in this section is about craters—the scars left by the impacts of comets and asteroids on the Earth, Moon and other bodies in the solar system. It provides opportunities for your students to actually produce craters and see what they tell us about the bodies that created them. The other activities are about the nature and composition of comets, and their motion about the Sun.

G Impact Site · July 18, 1994
Hubble Space Telescope · Wide Field Planetary Camera 2

Comet Shoemaker-Levy 9 Impact Site

BACKGROUND:
COMETS AND METEORS

Our ancestors were much more in tune with the night sky than those of us who live under bright city lights. They used the rising and setting of certain stars to tell them when to plant and when to harvest. They relied on familiar stars to find their way across featureless deserts and oceans. By necessity, they knew the sky intimately. Imagine their surprise and horror when a new star suddenly appeared, sprouting a tail streaming behind it like long, flowing hair. Over the course of a few months it would move relative to the other stars and finally disappear from view. Nearly every culture saw the sudden appearance of these "hairy stars" as portents of evil and doom. They believed kings were destined to fall, and famines or wars were sure to come, as the gods signaled their displeasure with humans through so clear a cosmic sign.

Today we know that the motions of celestial objects are controlled by natural forces, not gods. And we think of "hairy stars," or comets, as beautiful visitors to our part of the solar system, not as bad omens. Comets (the name comes from the Greek word for hair) are small, irregularly shaped lumps of dirty ice, no more than a few dozen kilometers across. They move on very elongated orbits around the Sun, which take them into the outer reaches of the solar system. About a hundred have orbits that bring them close to the Sun every 200 years or less (Halley's Comet, which returns every 76 years, is perhaps the most famous); most take thousands, or tens of thousands of years—or more—to revisit the solar neighborhood.

When they're far away, comets are very difficult to see. They're too small and too faint for even the largest telescopes to detect. But as they enter the inner part of the solar system, heat and radiation from the Sun causes some ice to turn to gas. Soon the tiny comet is surrounded by an enormous cloud of vaporized gas and loosened dust, that stretches up to 100,000 kilometers across, making the comet easy to see. A constant stream of radiation and a "wind" of particles given off by the Sun "blows" some of the gas and dust back away from the comet nucleus, forming the exquisite tails we associate with comets. The tails lengthen, spanning millions of kilometers, as the comet moves closer to the Sun. After sweeping around the Sun, the comet begins its return voyage to the outer solar system, its tail shortening as it moves farther away. Eventually, the gas cloud disappears, and the comet is, once again, hard to see.

Besides their intrinsic beauty, astronomers study comets because they may be made up of very old material that has remained relatively unchanged since the beginnings of the solar system. Formed in the frozen regions out past Uranus and Neptune, comets may be debris left over from the time when the planets formed, preserved because the giant outer planets gave them gravitational "kicks" and pushed them farther out in the solar system. Some can be found just outside the orbits of Neptune and Pluto, in an area known as the Kuiper Belt, after the astronomer Gerard Kuiper who first suggested they might be there. Billions more reside in an enormous, thick shell, the so-called Oort Cloud (named after astronomer Jan Oort), that begins hundreds of times farther away than Pluto and extends halfway to the nearest star. Occasionally something happens to disturb the orbit of a comet—perhaps a near collision with another comet, or the gravitational tug of Neptune, or a slight push from a passing star—and sends it hurtling toward the inner solar system and the Sun. Astronomers can then study it and learn more about the material out of which the planets formed.

People sometimes think that comets streak across the sky. They don't. They do move relative to the background stars, but the motion is usually so slow that you'll only see it if you study the comet's position in the sky night after night. Meteors, however, do flash across the sky, blazing brightly for a second or two before disappearing. Meteors are small grains of dust, no larger than sand or the "dust bunnies" that collect under your bed when you haven't cleaned recently, that can be found in the space between planets. If they happen to run into the Earth, friction with air molecules in our atmosphere causes them to burn up completely. They never reach the ground. Their "death" is the bright streak of light we see blazing across the sky, sometimes called by the awkwardly inaccurate name "shooting star."

If you go outside away from city lights and watch the night sky, you might see a few meteors in an hour's worth of observing. But sometimes you can see tens—even a hundred—meteors an hour. These periods of peak meteor activity are known as meteor showers, and occur on the same nights every year. The grains of dust in meteor showers come from comets. When a comet swings past the Sun, the dust in its tail gets left behind, staying close to the path the comet followed. As the Earth moves in its orbit around the Sun, it occasionally crosses the stream of dust left by a comet, and a meteor shower results. The Earth crosses the same dust stream at the same point in its orbit every year and on the same day, which is why meteor showers can be predicted with such accuracy.

During a shower, all meteors appear to come from the same part of the sky, called the radiant. Showers are known by the name of the constellation in which the radiant appears. For example, the most reliably spectacular meteor shower each year is probably the Perseids, which peak on the night of August 11-12. In this case, the meteors begin in the constellation of Perseus, before streaking off in all directions across the sky.

On rare occasions, rocks larger than grains of dust run into the Earth's path. If they're big enough, they can survive their fiery passage through the Earth's atmosphere and strike the ground. Technically, a piece of dust or rock moving through space is a meteoroid, which then becomes a meteor as it streaks through the atmosphere, and a meteorite if it survives and hits the ground. Meteorites are generally not associated with comets. Instead, they are thought to be fragments from collisions involving asteroids, the small rocky objects that range in size from pebbles to bigger than a mountain and are found primarily between the orbits of Mars and Jupiter. Asteroids are thought to be debris that could not coalesce into a planet when the solar system formed because of gravitational disruption caused by the giant planet Jupiter. Over the years, collisions between asteroids and pieces of asteroids have created many small chunks of rock that move throughout the inner parts of the solar system, and every once in awhile run into the Earth.

Most meteorites are small enough—a few pounds—that they cause little damage when they hit. Most land in the water that covers 2/3 of the Earth's surface. Very rarely they may punch a small hole in a roof or smash in the hood of a car. There are only two documented cases of a person being hit by a meteorite. Annie Hodges of Sylacauga, Alabama was napping on her couch on November 30, 1954, when an eight-pound meteorite crashed through the roof. It bounced off a large console radio and hit her in the arm and then the leg, leaving her badly bruised but otherwise okay. Then, on the afternoon of June 21, 1994, José Martín and his wife, Vicenta Cors, were driving in Spain from Madrid to Marbella. As they zoomed past the town of Getafé, a three-pound meteorite smashed through their windshield on the driver's side, ricocheted off the dashboard, and bent the steering wheel, breaking the little finger on Martín's right hand. It then flew between the couple's heads, and landed on the back seat. Martín managed to pull over safely to the side of the road, and, except for the broken finger, they were unhurt.

On rare instances, once every 100,000 years or so, rocks the size of large boulders or bigger strike the Earth. These can cause significant damage. The Earth's surface bears the scars of some of these collisions, large craters tens, even hundreds, of kilometers across. Many others have been washed away by rain, wind and volcanic activity. Scientists think an asteroid ten to fifteen kilometers across hit the Yucatan Peninsula of Mexico 65 million years ago. It may have hastened the extinction of the dinosaurs and many other species in a prolonged darkening of the skies from the dust of its explosion and resulting fires. The collision in the summer of 1994 of Comet Shoemaker-Levy 9 with Jupiter vividly demonstrated that such collisions can still occur in the solar system. Astronomers have begun to inventory the debris that litters the solar system near the Earth—comets, asteroids and smaller chunks—in hopes of finding out, far enough in advance to do something, if any will one day pose a threat to Earth. A powerful rocket explosion on or near a threatening object could give it the gentle nudge needed to miss us, avoiding the kind of catastrophe last witnessed by the dinosaurs.

EXPERIMENTING WITH CRATERS

ACTIVITY E-1

GRADE LEVEL: 4-9+

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What's This Activity About?

Our explorations of the solar system have revealed that almost every object with a solid surface shows evidence of cratering from impacts. Planets, moons, asteroids, and even comets show craters. The only surfaces where craters are not visible include the gas planets, without a solid surface, or moons like Jupiter's Io, with continuous volcanic outflows and changing geologies that cover the craters.

In this GEMS activity, students experiment with the cratering process. They can investigate how speed and size of the impacting body influence the shape and depth of craters, and how the surface material is disrupted. The activity is fun for students, and rich with scientific applications. It is also extremely well-presented, thorough, and easy to follow.

What Will Students Do?

Students drop rocks to create craters in shallow pans of flour and cocoa. By varying the size and speed of the impacting bodies, students will determine how the impactors affect the shape and depth of the resulting crater.

Tips and Suggestions

- This activity cannot simulate the tremendously large explosion that scientists know occurs when an object moving at great speed strikes a surface. It is the explosion that liquefies and vaporizes surrounding material, often including the impacting body. The melted material can create the smooth, rounded appearance and the central peak of most craters.
- To help emphasize the enormous energies released in the explosive impact of real meteoroids, explain that actual meteoroids travel as much as *6,000 times faster* than the rocks that students drop.
- Prepare students for this activity by showing slides of craters in the solar system.
- Experiment by making a "crater chain" similar to those seen on our Moon and on Callisto (Jupiter's outermost large moon). To create such a chain, the impactor needs to be a loose collection of material, like a handful of gravel. This experiment models the impact of a comet-like body similar to Shoemaker-Levy 9 that crashed into Jupiter in July, 1994.

What Will Students Learn?

Concepts
- Craters
- Impacts

Inquiry Skills
- Experimenting
- Comparing
- Measuring
- Reasoning

Big Ideas
- Simulations
- Energy
- Interactions

Activity 2: Experimenting With Craters

Overview

Craters are among the most fascinating features of many moons. In this activity, your students experiment to find out more about what causes the various features of impact craters, including the rim of mountains around the edge, and the streaks or rays that fan out from large craters. What they learn in this activity about our own Moon, Luna, they can later compare and contrast to what they find out about the moons of Jupiter.

What You Need

For the class:

- ❑ Slide set including:
  - # 12 Earth's Moon
  - # 13 Close-Up of Large Crater
- ❑ 1 slide projector and screen
- ❑ 1 or more brooms or whisk brooms to clean up spills
- ❑ 1 pair of scissors or a paper cutter (to cut the centimeter rulers off the student data sheets)
- ❑ one container instant chocolate milk powder. (Note: Real cocoa has also been used, but it tends to clump and to over-darken the flour too quickly.)
- ❑ three or four 5-pound packages of white flour

For each team of 4 students:

- ❑ 1 shallow basin (to be filled with about 3 to 5 inches of flour) Examples: a dishpan, a heavy aluminum roasting pan, or cardboard box. To be sure to have enough, you may want to ask a student from each group to bring in a dishpan from home for the day of the activity. They don't all have to be the same size.
- ❑ 1 cup or small plastic container (to be filled about one-third full with powdered instant chocolate milk mix)
- ❑ an old newspaper
- ❑ three rocks: small, medium, and large with diameters **about**: .5 cm ($\frac{1}{4}$ inch), 2 cm ($\frac{3}{4}$ inch) and 4 cm (about 1 $\frac{1}{2}$ inches)
- ❑ 1 spoon (plastic or metal)

For each student:

- ❑ 1 pencil
- ❑ 1 "Craters" activity sheet (master on page 28)

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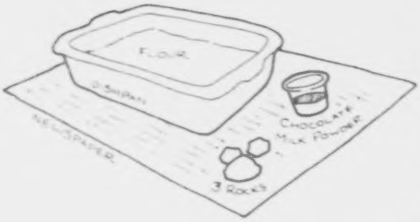
Getting Ready



1. Before the day of the activity, collect and sort the rocks needed for all the groups.

2. Make one copy of the "Craters" data sheet for each student (master on page 28). With scissors or a paper cutter, cut the centimeter rulers from the bottom of the data sheets.

3. Assemble sets of materials for the teams: newspaper, a dishpan filled with flour 3 to 5 inches deep, a cup about one-third full of instant chocolate milk mix, and three different-sized rocks. Have data sheets, paper rulers, and pencils handy, but separate from the other materials. Keep one set of all the materials handy near the place where you will demonstrate the activity.

4. Try the cratering activity yourself so you will know what to expect. Weather permitting, some teachers prefer to do this activity outside for more space and less cleanup. Decide whether your students will do the activity indoors or outdoors.

5. In these activities, there is first free exploration and then more focused cratering experiments that use data sheets. You will need to get the attention of your whole class for instructions before they begin both the free exploration and the more focused experiments. We recommend gathering your class away from the materials for both of these introductions. Some classrooms do not have enough space for students to leave the materials and gather for the second set of instructions. If this is the case, consider explaining all parts of the activity before distributing any of the materials. Read over the lesson, and decide if you'll need to modify your introduction in this way.

6. Set up the slide projector and have slides #12 and #13 ready for viewing (front side of the Moon and close-up of a crater). Prepare to darken the room by drawing curtains or shades.

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Meteors and Craters

1. Tell the class that the name of Earth's Moon is ***Luna***. Encourage students to begin thinking about Luna by asking them to imagine landing on the Moon's surface.

> What do you imagine the surface of our Moon is like?
>
> What would it feel like to be walking on Luna?
>
> What would you see around you?

Slide 12

2. Dim the room lights and turn on the slide projector. Show slide #12, the image of the Earth's Moon. (This is the side of the Moon that always faces Earth.) Tell them that this is how our Moon would look if viewed through a small telescope.

Between the years 1969 and 1972, six spacecraft from the United States visited the Moon, enabling twelve people to walk on its surface. They had to wear space suits, which create Earth conditions in unearthly places. The space suits carry air to breathe, air pressure that keeps the blood from boiling, and protects the wearer from burning in the sunlight or freezing in the shade. Since the Moon's gravity is one-sixth Earth's gravity, the astronauts are able to jump higher than on Earth. Since they also fall more slowly, they seem to move in slow motion.

3. Ask, "What do you see on the Moon's surface?" Accept their responses (for example, light areas, dark areas, craters etc.). If somebody mentions craters, have them point out an example of one for the class. If craters are not mentioned, point out a large one and identify it as a crater. Explain that craters are big "dents" or holes in the Moon's surface. Do not go into detail about other surface features at this time.

4. Turn on the room lights and turn off the slide projector. Ask, "What causes craters on the Moon?" [Most students will have an answer for this question and may use terms such as: meteors, asteroids, big rocks, comets, etc.]

5. Ask students if they know what a ***meteor*** is. [A rock from space falling toward a planet or moon.]

6. Ask your students if there are craters on the Earth. If anybody has visited a crater site, have them share their experience with the class. Explain that the Earth has many craters. Some were caused by volcanoes. Others, called ***impact craters,*** were made by meteorites. Ask, "Why do we see very few impact craters on the Earth?" [The Earth has rain and wind which erode away the evidence of most craters.]

7. Explain that Earth's atmosphere prevents small meteors from reaching the surface, because when a meteor falls toward a planet with an atmosphere, it "rubs" against the air.

Since the terms are often confusing, you may wish to explain that a ***meteoroid*** *is a rock in space; a* ***meteor*** *is the same rock falling through the Earth's atmosphere, creating a streak of light (sometimes also called a "shooting star"). Fragments of meteors that survive the fiery trip through the atmosphere and land on the surface are called* ***meteorites****. However, it is not important for students to memorize these terms.*

8. Have your students rub their hands together quickly for about ten seconds (counting "one-thousand-one, one-thousand-two," etc.) Ask what they feel. [Heat.] Tell them that if they could rub fast enough they would create enough friction to light a fire.

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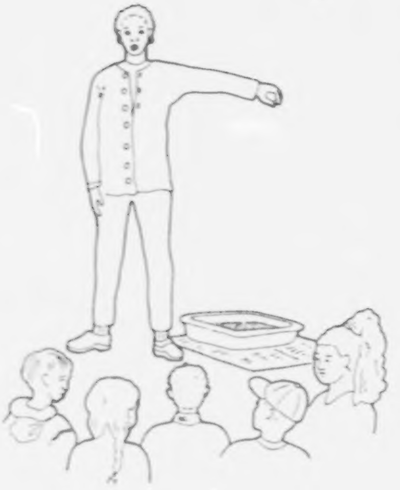

9. Explain that, in a similar way, the flash of light they see from a "shooting star" or meteor is a white-hot glow produced by the heat of friction between the meteor and the air, as the meteor falls through the Earth's atmosphere. Many smaller meteors burn up before hitting the Earth's surface—that doesn't happen on the Moon, because the Moon has no air to rub against, which is one reason why the Moon has lots of craters.

Making Craters

1. Tell the class that they will now investigate what happens when a meteoroid hits a solid surface like that of the Moon.

2. Tell the students that they will use a pan of flour and three different size rocks to investigate meteor craters. The flour will represent the surface of the Moon and the rocks will be the "meteoroids."

3. Demonstrate the technique:

- Place an old newspaper and a pan of flour on the floor near your feet.
- Sprinkle a light coating of instant chocolate milk mix on the surface of the flour to create a contrast that will help make changes more visible.
- Hold out a medium-sized rock at about shoulder level. Don't actually drop the rock. Tell the students that they are to drop, **NOT THROW,** their rock onto the flour.
- After they drop their "meteoroid" they observe what happens to the flour.

4. Ask, "What do you think will happen?" and have several students make predictions.

5. Explain that they will work in groups, and take turns dropping the rocks into the flour. Point out that they need to observe very carefully so they can describe what happens on impact and what features are created on the "lunar" surface. It's not necessary to smooth the flour and apply chocolate milk mix after each try.

6. Emphasize how important it is to drop the rocks carefully, and **never to throw the rocks,** or act in any way that is unsafe. (Since flour underfoot can be slippery, if any gets on the floor it should be swept up immediately. Demonstrate how to

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sweep flour onto a sheet of newspaper and return it to the basin.)

Free Exploration

1. If you feel it would be helpful, give the students a few minutes as a whole group to discuss ways to take turns making the craters. You may also want to have them meet in their small groups to agree on a system for taking turns **before** you distribute their materials.

2. Distribute the materials to the teams and let them freely explore the materials and practice making craters for about five minutes. Do not pass out the data sheets yet.

It's okay that there will be chocolate milk powder mixed in the flour as teams repeatedly level and resurface the flour. If the mixture becomes very dark, or if a team has used up all its chocolate milk powder, suggest that they sprinkle flour on the surface instead of the powder to create a contrast.

3. After free exploration gather students away from the materials and ask the students: "What did you find out?" What features did your craters have?"

4. You may want to have a few volunteers draw what they saw on the chalkboard. As students describe the various features, write some terms on the board. [The impression left on the surface is called a ***crater basin.*** Students may have noticed a ***rim*** around the edge of the basin and streaks or ***rays*** that radiated outward from the crater.]

Meteor Experiments

1. Explain the procedures for the two experiments, as follows:

2. Remind your students that they saw craters of many different **sizes** on the slide of the Moon. Ask, "What might affect how **big** craters will be?" [Students may suggest meteoroid size or weight, speed at impact, direction, or type of surface material.]

3. Explain to the class that the teams will now conduct experiments to find out how two of those factors affect the size of the craters: the **size of the meteoroid** and the **speed of impact.** Hold up a data sheet and explain the two experiments:

Experiment #1: Size of Rock

- Tell the class that in order to learn more about how the size of the rock affects the size of the crater, teams will make three craters with each of their three rocks (a total of nine craters for Experiment #1). Teams will drop three different size rocks from the same height. They are to

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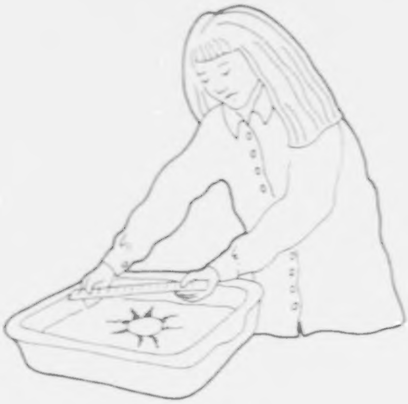
drop each rock three times, and record the crater diameter after each drop.

- Ask why it will be important to drop all the rocks from the same height. [Then, if the crater size varies, they'll know it's because of the size of the rock.] Suggest that they use one team member's shoulder height as a standard for every trial.

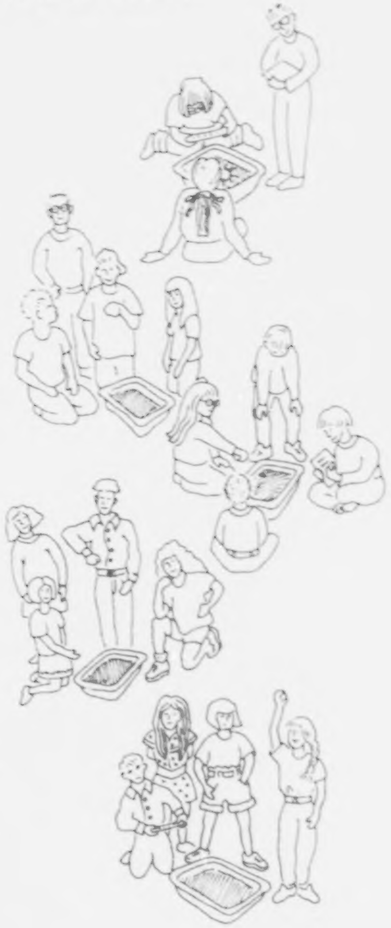
- Demonstrate how to remove the rock from the flour very carefully, so you don't disturb the crater.

- Show how to measure the diameter of the crater, using a paper centimeter ruler. Show where to record the crater diameters on the data sheet.

- Demonstrate how to jiggle the container back and forth a few times to level the flour, and how to sprinkle more chocolate milk powder on top when the surface needs it.



You may want to have the students calculate averages, although the results may be evident without it.



Experiment #2: Speed of Impact

- Explain that this time, the team will choose only one rock to make all their craters, but they will drop the rock from different heights: knee-high, shoulder-high, and as high as they can reach when standing on the floor. Make sure that the students understand that a rock gains speed as it falls, so the farther it falls, the faster it will be going when it hits the flour. They will make three craters from each of the three heights. (A total of nine craters for Experiment #2.)

- Ask why they should use the same rock when they are experimenting with different speeds of "meteors." [If they used different rocks *and* different heights, they won't know which made the differences in crater sizes.]

- Point out that knee-high, shoulder-high, and as high as they can reach, may vary for different students, and ask them for ideas about how to keep the height standard on all three tries. [They could take turns dropping the rock, but use one student's knee, shoulder, and outstretched arm as the standard for all tries.]

- Show where to record all crater diameters in this second experiment.

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Students Experiment

1. Make sure the students understand the two experiments. Hand out the data sheets and paper rulers and have them begin.

2. Circulate during the experiments, checking to be sure students are working safely and cooperatively in their teams.

3. If a team finishes early, suggest that they extend their investigations in Experiment #2 by, for example, **carefully** standing on a chair to drop the rock. (Older students may want to extend their investigation by observing or measuring crater *depths* created by various sizes or speeds of "meteoroids." The long "rays" that radiate from their "craters" could also be measured.)

4. As teams finish, have them return their equipment to the materials area and clean up. Students should keep their data sheets for the discussion.

The "Background for Teachers" contains additional information on past and present experiments and theories about craters.

Discussing the Results

1. Gather the class in the discussion area.

2. Have the class look at their data for Experiment #1, comparing meteor sizes, and ask them to describe what they observed and recorded. Ask, "Does the size of the meteoroid have anything to do with the size of the crater?" [Your students' experimental data is likely to vary, but many students will find that crater size increases with the size of the meteoroid.]

3. Ask the students what they can conclude from Experiment #2, about meteors that have struck with different speeds. [Again, student data will vary, but many students will conclude that the faster the meteor, the bigger the crater.] You may want to add that scientists estimate that real craters caused by actual meteor impacts are about 20 times the diameter of the meteor itself.

4. Show the slide of Earth's Moon again. Ask volunteers to point out some of the features of craters on the Moon that they recognize from their experiments.

5. Show the close-up of a Moon crater (Slide #13) and ask for more observations and comments. Your students may notice that all the lunar craters appear round. No matter the initial shape of the meteor (or the angle of its impact) the resulting explosion will always form a round crater.

Students may notice the central peaks in some craters. Modern scientists have been able to simulate actual meteor impacts with rocks fired from powerful guns (at 30,000 mph). At such speeds the meteor does not stop moving at the moment of impact. Friction rapidly heats the meteor and a tremendous explosion occurs. (Imagine quickly trying to change all the energy of a room-sized meteor traveling at 30,000 mph into heat!) If the meteor is large and fast enough, the ground liquefies, forming a crater with a rim around it. In large impacts the rim collapses, and the liquefied material rushing back into the center of the crater forms a mountain in the middle. Debris thrown out by the explosion forms rays that may extend for hundreds of miles. On Earth, small pieces of a meteor are sometimes found at the impact crater, confirming that the crater was caused by a meteor impact.

Slide 13 – "Crater close up, Earth's Moon"

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Going Further

1. Craters in Liquids

For each group of four to six students, you'll need a cup of water, a medicine dropper (optional), and 1 blank sheet of paper. Begin by showing the slide of the close-up of a Moon crater again, and point out the central peak.

Explain to the students that they will experiment to see what happens when a meteor falls into a liquid, and that one of the features they should look for is the central peak. Demonstrate as follows: Pour a cup of water into a pie pan. If you are using medicine droppers, show how to hold the dropper about a foot over the pan and allow a drop of water to fall into the pan. Or, demonstrate how to dip a finger into the water so that a drop hangs from it, and shake the drop loose so it falls into the water. (Although the drop of water is a little bigger with the dropper, the fingertip method works fine.)

Encourage all members of the team to observe what happens from the side and from just above the surface of the water. Have the students take turns releasing drops and observing what happens. Each team should discuss their results and draw what they see on their papers. The students might identify the following:

— As soon as the drop hits, it goes below the surface of the water, making sort of a "crater."

— Ripples come from the center, hit the walls of the pan, and bounce back and forth.

— A mound of water forms in the center of the crater, right after the drop is dropped. It may *seem* as if the drop "bounces" back after it hits the water.

Ask the students what crater features they saw that they may not have seen in the experiment with solids. [***concentric circles, ripples, and central peaks.***] Explain that very large meteors that have struck the Moon move so fast that they melt the rocks. In these cases, even though the surface may have been solid before the impact of the meteor, we can sometimes see the central peak caused when the Moon's surface turned to molten rock for a few minutes, then solidified before the peak had a chance to become level again.

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2. Moon Mapping

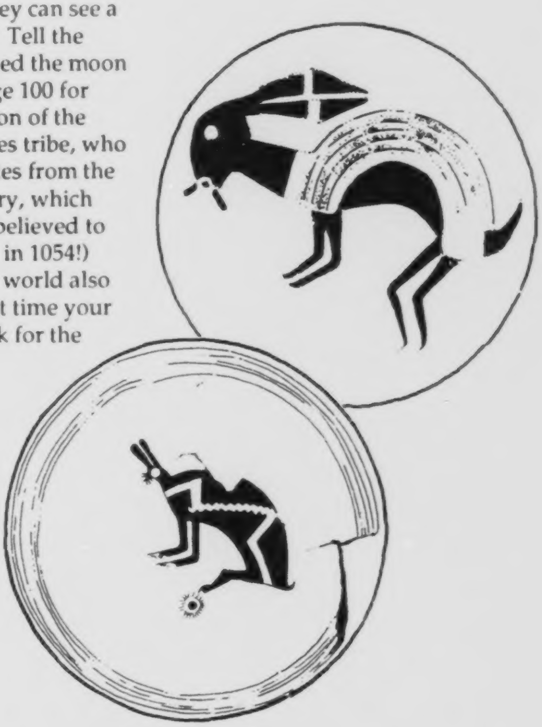
If you wanted to land a spacecraft or build a lunar settlement on the Moon, where would you choose? Before real astronauts landed on the Moon, they needed to study a map of the Moon. Hand out a copy of the Moon Map (page 29) to each student. Project the slide image of the full moon (slide #12) and have students compare the features on their map with those on the Moon's surface.

Have the students work in pairs or groups and assign a particular "ocean," "sea," or "bay" for them to find. They should locate it first on their map and then identify the corresponding feature on the slide. Those who finish quickly can practice finding other features. Have volunteers from each group get up and point out their feature to the rest of the class. (There are 12 oceans and seas labeled on the map.)

For a more difficult challenge, assign each group a crater or mountain range to find. Invite the students to use their lunar maps when observing the real Moon in the sky. Encourage them to use a pair of binoculars if available. (Through binoculars, the moon-view will match the map, but through a telescope, the image is reversed!)

3. Rabbit in the Moon

Show the moon slide again. Ask the students if they can see a rabbit. Ask where are the ears? Where is the tail? Tell the class that many Native American cultures associated the moon with a rabbit. Duplicate the rabbit pictures on page 100 for each student. Tell them that the rabbit is a depiction of the rabbit in the moon found on pottery of the Mimbres tribe, who lived in what is now the Southwestern United States from the 9th to 12th centuries. (One piece of Mimbres pottery, which shows a burst of light below the leg of a rabbit, is believed to depict the supernova that created the Crab nebula in 1054!) The Japanese and many other cultures around the world also visualize a "rabbit in the moon." Suggest that next time your students look at the real moon in the sky, they look for the rabbit—it's easy to see!



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Name ______________________________ Date______________

CRATERS

Experiment 1: Size of Meteoroid

How will the size of the rock affect the size of the crater?

Record the Crater Diameter for:

	1st try	2nd try	3rd try
Small rock	______	______	______
Medium rock	______	______	______
Large rock	______	______	______

What can you conclude?

____

____

____

Experiment 2: Speed of Meteoroid

How will the speed of impact affect the size of the crater?

Record the Crater Diameter for:

	1st try	2nd try	3rd try
Slow	______	______	______
Medium	______	______	______
Fast	______	______	______

What can you conclude?

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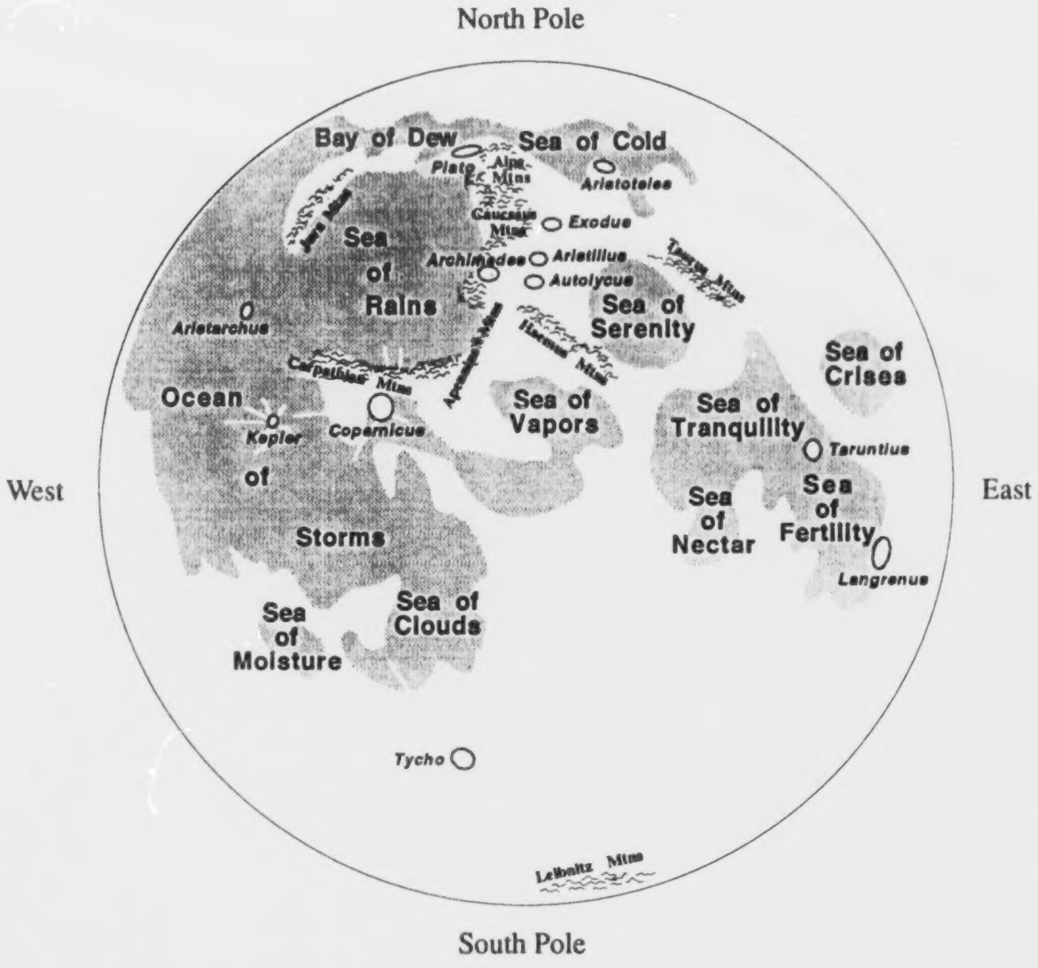
MOON MAP


North Pole
Bay of Dew
Sea of Cold
Plato
Alps Mtns
Aristoteles
Jura Mtns
Caucasus Mtns
Exodus
Sea of Rains
Archimedes
Aristillus
Autolycus
Taurus Mtns
Sea of Serenity
Aristarchus
Haemus Mtns
Apennine Mtns
Carpathian Mtns
Sea of Crises
Ocean of Storms
Kepler
Copernicus
Sea of Vapors
Sea of Tranquility
Taruntius
West
East
Sea of Nectar
Sea of Fertility
Langrenus
Sea of Moisture
Sea of Clouds
Tycho
Leibnitz Mtns
South Pole

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MAKE A MODEL COMET

ACTIVITY E-2

GRADE LEVEL: 4-6

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What's This Activity About?

Students may have heard about Halley's Comet, but few will have actually seen the incredible sight of a comet hanging motionless in the evening sky, with its enormous tail pointing away from the Sun. The activity shows students the relative sizes of the *coma*—the evaporated gas around a comet's nucleus—and the *tail*, composed of gas and dust that form when a comet comes close enough to the sun. This activity complements the next, "Making a Comet in the Classroom."

What Will Students Do?

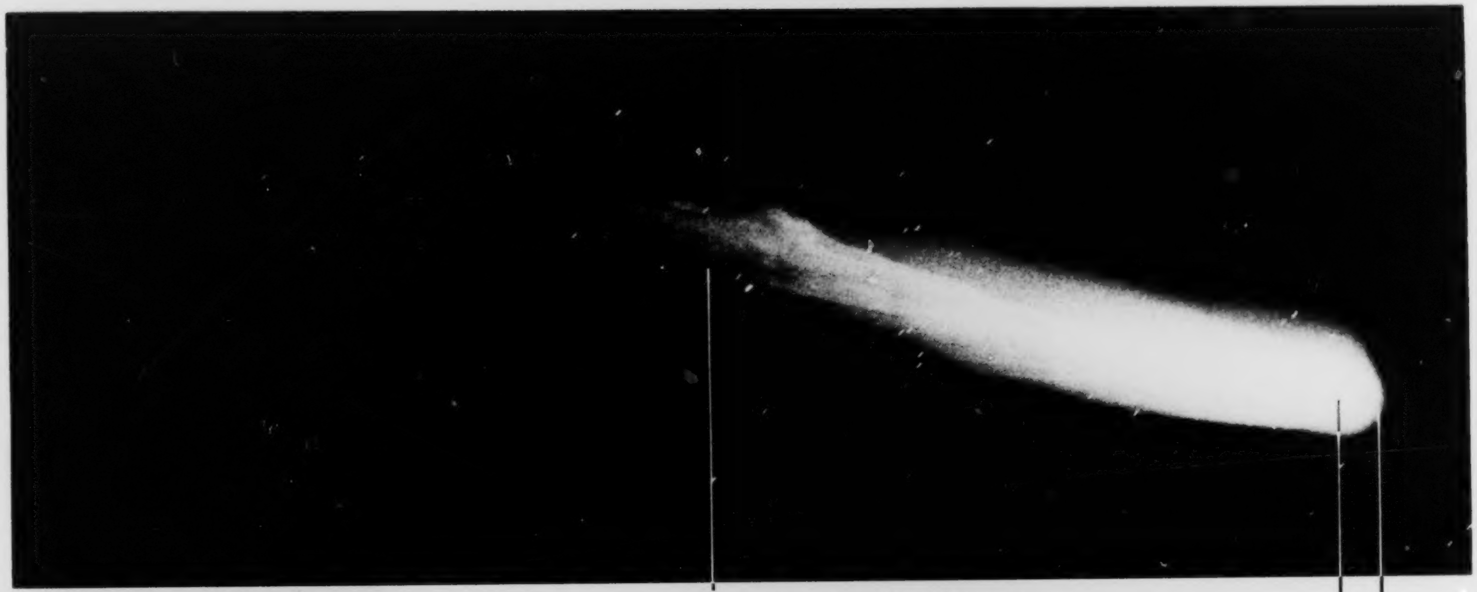
Students use cotton balls and string to create a scale model of a typical comet's coma and tail as the comet approaches the Sun.

Tips and Suggestions

- Students may ask why the comet's tail flies off behind the nucleus and coma. Pressure from sunlight, and also from charged particles streaming from the Sun (called the *solar wind*), pushes dust and evaporated gas from the comet.
- You can make the tail "flutter" by using a hand-held hair dryer to represent the solar wind, and explain how the tail always points away from the Sun as the comet swings past in its highly elongated orbit.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Comets	Describing	Scale
Coma and tail		Structure



Tail—The gas and dust that are blown out of the coma when the comet nears the sun. It may be 1 million to 100 million km (600,000 to 60 million mi) long.

Nucleus—The frozen central core usually 2 to 10 km (1 to 6 mi) across.

Coma—A gas and dust cloud that forms around the nucleus. It grows as a comet approaches the sun, becoming as large as 10,000 to 1,000,000 km (6,000 to 600,000 mi) across.

WHAT IS A COMET

A comet is like a dusty iceberg that races around the sun at speeds as fast as one million km per hour (600,000 mi per hour). It is composed not only of frozen water, but other frozen gases, such as ammonia and methane. Ammonia is the strong smelling part of many cleaning liquids and methane is a type of natural gas used in some heaters.

Most comets are always far from the sun and frozen solid. A few comets, however, periodically travel close to the sun. When one of these comets approaches the orbit of Jupiter or around 800 million km (500 million mi), it begins to melt from the sun's heat. A cloud of gas and dust forms which is called the comet's coma (pronounced cō-ma). It is usually larger than the Earth and may be as wide as 800,000 km (500,000 mi). The core of the comet remains solid and is called the nucleus.

When the comet gets near the orbit of Mars or around 250 million km (150 million mi) from the sun, the gas and dirt in the coma are blown away. A long tail forms that may be 100 million km (60 million mi) long. It is the tail that has inspired the continual search to understand these beautiful and still mysterious comets.

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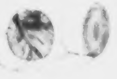
Make a Model Comet

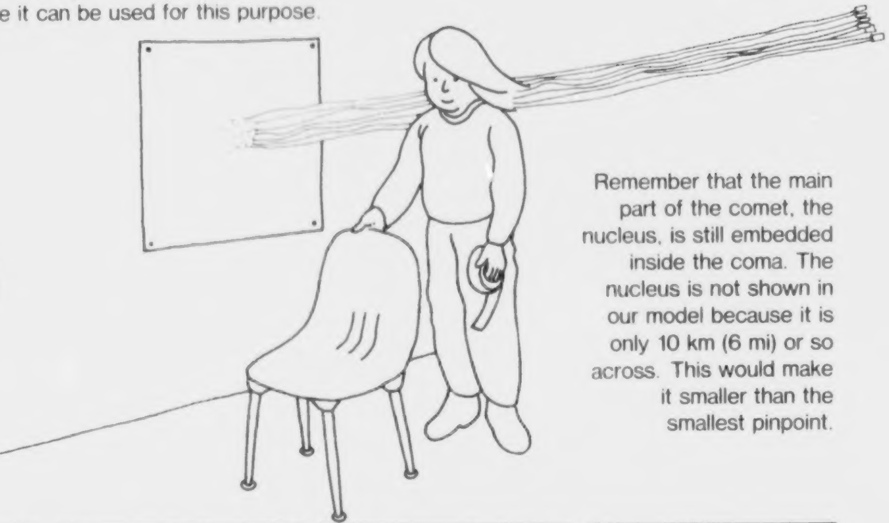
Photographs of comets do not reveal how big the tail is compared to the coma or nucleus. In this activity you construct a scale model of Halley's Comet to understand its immensity. For this activity use 1 cm = 100,000 km (1 in = 150,000 mi).

This activity is best done on a wall. Be sure it can be used for this purpose.

What you need

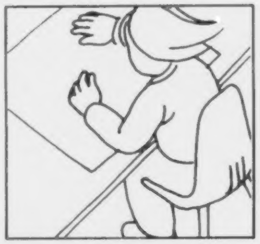
- Cotton
- White crepe paper or string
- Glue
- Sheet of light-colored paper
- Tape or thumb tacks



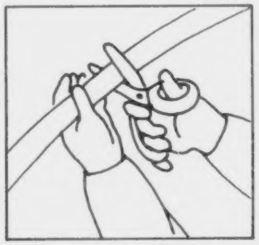


Remember that the main part of the comet, the nucleus, is still embedded inside the coma. The nucleus is not shown in our model because it is only 10 km (6 mi) or so across. This would make it smaller than the smallest pinpoint.

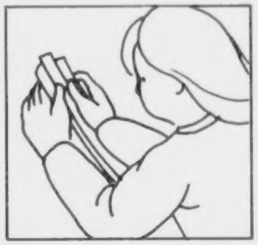
What to do



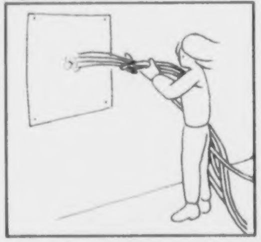
1. Glue a cotton ball that is about 5 cm (2 in) across near the center of the paper.



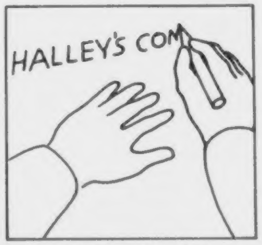
2. Cut 10 to 15 strips of crepe paper or string that are 4 to 5 meters long (12 to 15 ft).



3. Tack up the paper sheet with the coma on it at one end of the wall. Gather one end of all the crepe paper or string strips. Tape or glue them next to the coma so that they can easily be stretched along the wall.



4. Stretch the crepe paper or string along the wall, tacking or taping the other ends so that the tail fans out slightly like in the photos of comets in this book. Put waves or knots in the tail for a more realistic effect.



5. Add labels to identify the comet and its different parts, such as the coma and tail.

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MAKING A COMET IN THE CLASSROOM

ACTIVITY E-3

GRADE LEVEL: 4-9+

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What's This Activity About?

Comets are wonderfully mysterious things for our students. Since Halley's return in 1985, the only widespread images of comets have been artistic pictures prompted by the Shoemaker-Levy 9 impact at Jupiter in 1994. This activity give students a chance to observe the uneven surface, dark composition, delicate character, and even venting of trapped gas of a "mock" comet. All of these traits are based on the information scientists have gathered from watching comets over the years, and especially from the fly-by of Halley.

"Making a Comet in the Classroom" can be done as a teacher demonstration or a student activity and is one of the most fun and accurate activities about comets.

What Will Students Do?

Students will observe as a comet is created from common ingredients (dry ice, dirt, water). For later grades, with appropriate facilities and enough dry ice, students can make their own comets.

Tips and Suggestions

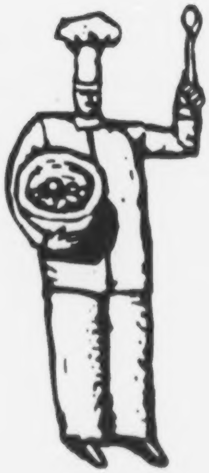
- Be careful with the dry ice. Always use gloves, or oven mitts! If students handle the dry ice, review proper safety procedures and what to do if the ice contacts skin.
- For lower grades, use this activity as a demonstration. Ask students to note the proportions of ingredients, the color and surface characteristics, the jets, and the slow disintegration.
- For later grades, have the students create their own comets by mixing all of the ingredients in a plastic bag. If you're brave, allow the students to let their comets "fly" by throwing them outside in an open area.
- To simulate movement of the comet through the solar system, carry the comet as you walk around a bright bulb (the Sun) in a darkened room. Far from the bulb, walk very slowly, and comment on the low temperature and feeble light. Closer to the bulb, describe passing Saturn and Jupiter, and near Mars warming up so much that the tail begins to form. Walk more quickly toward the bulb (the increasing gravitational pull between the Sun and the comet causes the comet to travel faster), swing around it, and head away, tumbling the comet as you go. Follow up this activity with pictures of Halley's comet, taken by the Giotto spacecraft as it flew by.
- Places to get dry ice: ice cream stores, grocery stores, butcher shops.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Composition of comets	Observation	Structure
Liquids and gases at different temperatures	Visualizing	Energy
Reflectivity	Describing	

Making a Comet in the Classroom

by Dennis Schatz
Pacific Science Center



A dramatic and effective way to begin a unit on comets is to make your own comet right in front of the class. The ingredients for a comet are not difficult to find and watching a comet being "constructed" is something the students will remember for a long time.

The "ingredients" for a six-inch comet are:

2 cups of water
2 cups of dry ice (frozen carbon dioxide)
2 spoofuls of sand or dirt
a dash of ammonia
a dash of organic material (dark corn syrup works well)

Other materials you should have on hand include:

an ice chest
a large mixing bowl (plastic if possible)
4 medium-sized plastic garbage bags
work gloves
a hammer, meat pounder, or rubber mallet
a large mixing spoon
paper towels

Dry ice is available from ice companies in most cities (look under "ice" in the Yellow Pages for a local source). Day-old dry ice works best, so you might want to buy it the afternoon before the day you do the activity. Keep the dry ice in an ice chest packed with newspaper and tightly closed. Most ice companies have a minimum on the amount of ice they will sell (usually 5 pounds). But having extra dry ice on hand will be useful because some will evaporate and also because it is advisable to practice this activity at least once before doing it with the class.

The Activity

Here are the steps for making a 6-inch comet (students make good baker's assistants for this exercise!):

1) Cut open one garbage bag and use it to line your mixing bowl.

2) Have all ingredients and utensils arranged in front of you.

3) Place water in mixing bowl.

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4) Add sand or dirt, stirring well.

5) Add dash of ammonia

6) Add dash of organic material (e.g. corn syrup), stirring until well mixed.

7) Place dry ice in 3 garbage bags that have been placed inside each other.
(*Be sure to wear gloves while handling dry ice to keep from being burned.*)

8) Crush dry ice by pounding it with a hammer.

9) Add the dry ice to the rest of the ingredients in the mixing bowl while stirring vigorously

10) Continue stirring until mixture is almost totally frozen.

11) Lift the comet out of the bowl using the plastic liner and shape it as you would a snowball.

12) Unwrap the comet as soon as it is frozen sufficiently to hold its shape.

Now you can place the comet on display for the students to watch during the day as it begins to melt and sublimate (turn directly from a solid to a gas—which is what carbon dioxide does at room temperature and comets do under the conditions of interplanetary space when they are heated by the Sun).

The comet is reasonably safe to touch without getting burned by the dry ice, but it is still best to have a spoon or a stick for the students to use while examining it. As the comet begins to melt, the class may notice small jets of gas coming from it. These are locations where the gaseous carbon dioxide is escaping through small holes in the still-frozen water. This type of activity is also detected on real comets, where the jets can sometimes expel sufficient quantities of gas to make small changes in the orbit of the comet.

After several hours, the comet will become a crater-filled ice ball as the more volatile carbon dioxide sublimates before the water ice melts. Real comets are also depleted by sublimation each time they come near the Sun. Ultimately, old comets may break into several pieces or even completely disintegrate. In some cases, the comet may have a solid, rocky core that is then left to travel around the comet's orbit as a dark barren asteroid.

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MAKE A COMET MOTION FLIP BOOK

ACTIVITY E-4

GRADE LEVEL: 4-6

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What's This Activity About?

Halley's comet is a "short period" comet, with an orbit extending just beyond the distance of Neptune from the Sun. By modeling its orbit with a sequence of images, students can observe that the comet's tail only begins to develop inside the orbit of Jupiter. They will see that the comet speeds up as it nears the Sun, and that the tail always points away from the Sun. Even though Halley will not return to the inner solar system until 2061, other non-periodic comets may approach the Sun in the near future, and they will follow the same pattern demonstrated here.

What Will Students Do?

Students cut out images of Halley's comet moving in its orbit around the Sun. Putting the images in sequence, they create a "flip book." Students can observe the comet's motion, its changing speed around the Sun, and the development and direction of its tail.

Tips and Suggestions

- Do not tell the students what properties to look for. After they use the flip books, ask them to form small groups and discuss their observations. Ask the groups to develop hypotheses for what they see. Bring the groups together to share results, and lead the discussion to sunlight, gravity, and the solar wind.
- Note that Halley's comet does not orbit within the plane of the solar system, as the flip book images might suggest. Students may even ask if Halley would ever collide with a planet, like Shoemaker- Levy 9 did with Jupiter in 1994. Halley's orbit, like that of most comets, is highly inclined to the plane of the planets. The comet spends most of its orbit far "below" the planets (for those of us in the Northern Hemisphere!), and only peeks into the path of the planets near the Sun.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Comets	Observing	Interactions
Solar Wind	Inferring	Patterns of Change
Orbits	Visualizing	

Make a Comet Motion Flip Book

Before the invention of movies, people made pictures appear to move by taking many photographs, one right after the other, and stapling them together. By flipping through the pictures quickly, the objects appeared to move. In this activity you see the motion of a comet using a flip book.

What you need:

These two pages.

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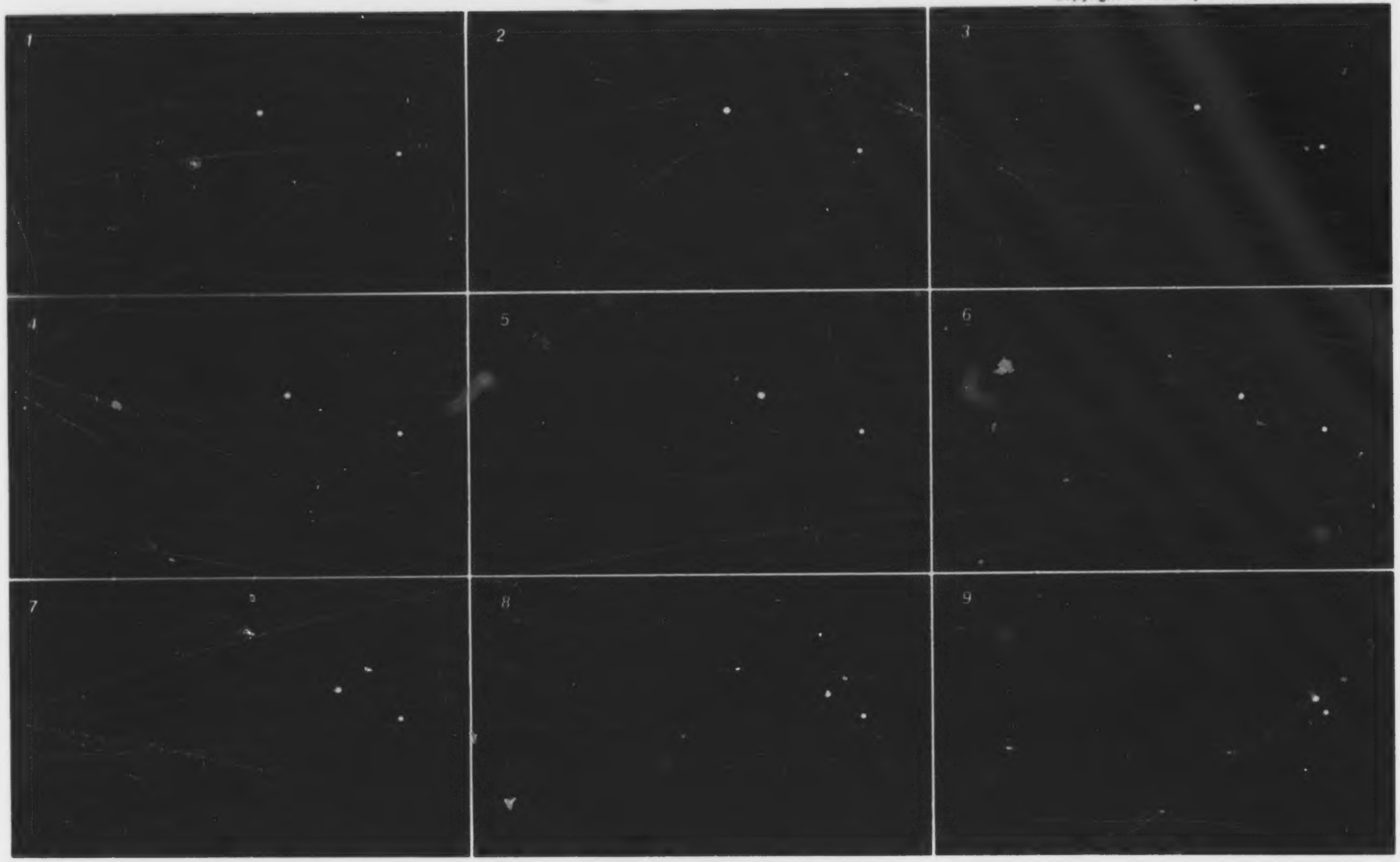

BEST COPY AVAILABLE

What to do:

1. Cut out the drawings on these two pages. Be careful to cut along the lines.

2. Stack them on top of each other with number one on top. Fan them out slightly to make them easier to flip through.

3. Flip through the pages several times to be sure the flipping motion is smooth. Then flip through them again to see if you can identify at least three things about comets and their motion.

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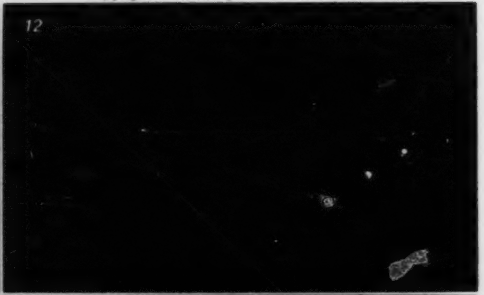
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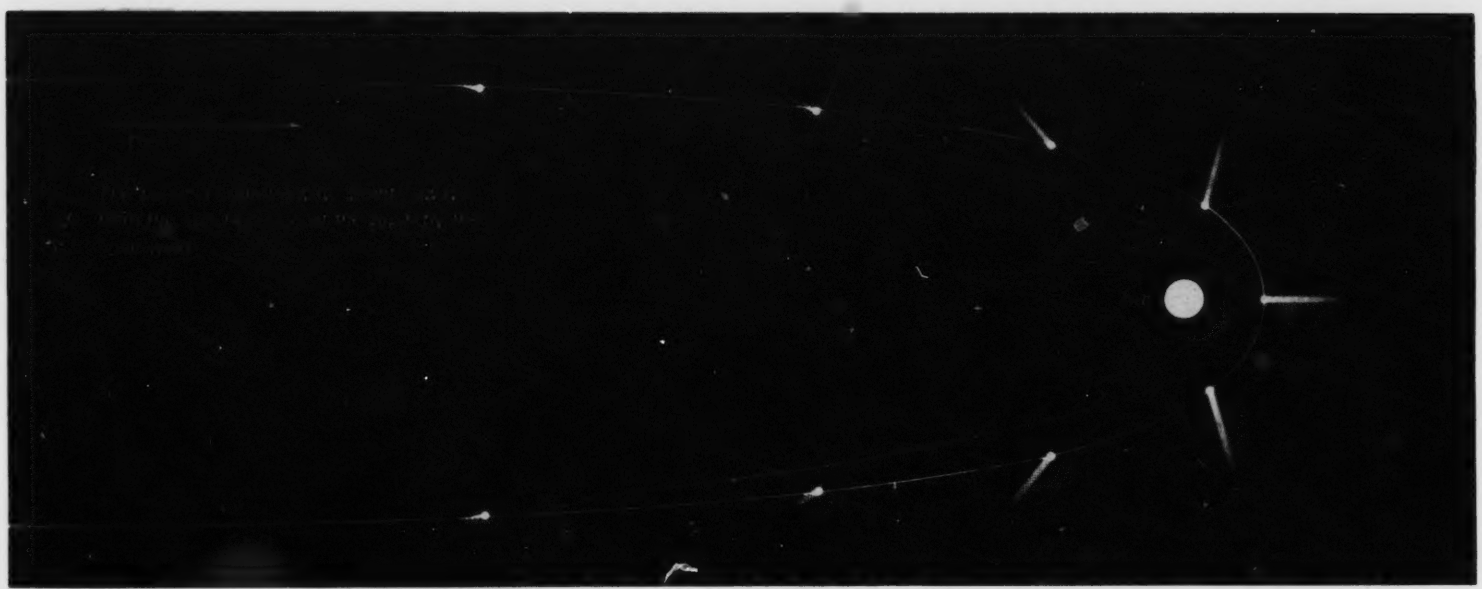

MORE ABOUT COMET MOTION

The flip book lets you see that the comet only forms a tail when it nears the sun. The comet begins to melt as it approaches the orbit of Jupiter at about 800 million km (500 million mi). The frozen gases are released to form the coma which increases in size as the comet approaches the sun. Most comets form a tail as they approach the orbit of Mars at about 250 million km (150 million mi). The tail usually increases in size until just after the comet's closest approach to the sun, when the reverse process begins.

The most dramatic and unexpected observation that can be made from the flip book is that the tail of the comet always points away from the sun. The solar wind, which always blows away from the sun, causes the tail to always point away from the sun in the same way that smoke from a smokestack moves away from the direction of the wind.

Notice when you flip the book that the comet moves slowly in its orbit when it is far from the sun and quickly when near the sun. It is easy to understand why, if we look at how the pull of gravity between the sun and the comet works. Gravity is a force that makes any object attract all other objects. The pull of the Earth's gravity keeps you attached to the Earth and the sun's gravity keeps the Earth and Halley's Comet in orbit around the sun. The pull of gravity is greater when the two objects are close together. Since the comet is being pulled harder when it is near the sun it will travel faster than when it is far from the sun.

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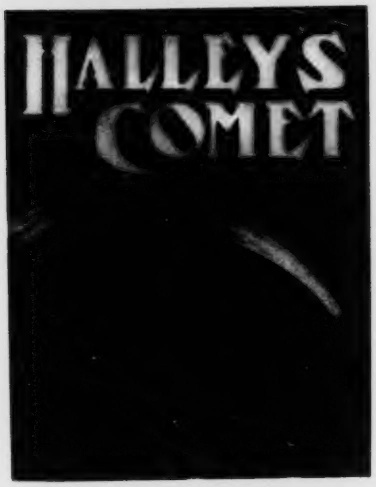


Resources for Exploring Comets, Meteors, and Meteorites

by Andrew Fraknoi
Astronomical Society of the Pacific
390 Ashton Avenue
San Francisco, CA 94112

Books or articles marked with a • are especially useful for those just becoming familiar with the subject.

RESOURCES FOR EXPLORING COMETS

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

Books on Comets

• Brandt, J. & Chapman, R. *Rendezvous in Space: The Science of Comets.* 1992, W. H. Freeman. The definitive popular book on comets and what we know about them.

Yeomans, D. *Comets: A Chronological History.* 1991, J. Wiley. A fascinating series of historical & anecdotal stories about comets in legend, history, and science.

Hall, L. *Searching for Comets.* 1990, McGraw Hill. The story of the spacecraft that explored Halley's Comet.

• Levy, D. *The Quest for Comets.* 1994, Plenum Press. Personal story of comet hunting and comet science by an enthusiastic amateur astronomer.

• Sagan, C. & Druyan, A. *Comet.* 1985, Random House. Superbly written and illustrated summary of comet legend and comet science, before the recent pass of Halley's Comet.

• Krupp, E. *Beyond the Blue Horizon.* 1991, Harper Collins. Includes a good section on comet legends from many cultures.

Articles on Comets in General

Benningfield, D. "Where Do Comets Come From?" in *Astronomy*, Sep. 1990, p. 28. On the Oort and Kuiper Belts, where comets originate.

Berry, R. "Search for the Primitive" in *Astronomy*, June 1987, p. 6.

Bortle, J. "Comet Swift-Tuttle: Worth the Wait" in *Sky & Telescope*, July 1993, p. 107.

Brandt, J. & Chapman, R. "Rendezvous in Space" in *Mercury*, Nov/Dec. 1992, p. 178. What we have learned about comets from spacecraft observations.

Levy, D. "How To Discover a Comet" in *Astronomy*, Dec. 1987, p. 74. A nice introduction by an amateur who has discovered several comets.

Green, D. "What to Do if You Discover a Comet" in *Sky & Telescope*, Oct. 1987, p. 420.

Pendleton, Y. & Cruikshank, D. "Life from the Stars" in *Sky & Telescope*, Mar. 1994, p. 36. On the possibilities that comets helped "seed" the Earth with the molecules of life.

Weissman, P. "Comets at the Solar System's Edge" in *Sky & Telescope*, Jan. 1993, p. 26.

Articles on Comet Halley

Berry, R. & Talcott, R. "What We Have Learned from Comet Halley" in *Astronomy*, Sep. 1986, p. 6.

Bortle, J. "Comet Halley: Newsmaker for 2000 Years" in *Sky & Telescope*, Aug. 1985, p. 126.

Gingerich, O. "Newton, Halley and the Comet" in *Sky & Telescope*, Mar. 1986, p. 230.

- Gore, R. "Halley's Comet '86: Much More Than Met the Eye" in *National Geographic*, Dec. 1986.
- Overbye, D. "Comet Halley: Once More with Feeling" in *Discover*, Dec. 1986, p. 86.

The March 1987 issue of *Sky & Telescope* magazine was devoted to what we learned from the 1985-86 pass of Halley's Comet.

Articles on the Collision of Comet Shoemaker-Levy 9 with Jupiter

Beatty, J. & Goldman, S. "The Great Crash of 1994: A First Report" in *Sky & Telescope*, Oct. 1994, p. 18.

Burnham, R. "Jupiter's Smash Hit" in *Astronomy*, Nov. 1994, p. 34.

Eicher, D. "Death of a Comet" in *Astronomy*, Oct. 1994, p.40.

Levy, D. "Pearls on a String" in *Sky & Telescope*, July 1993, p. 38. The story of the discovery of the comet.

O'Meara, S. "The Great Dark Spots of Jupiter" in *Sky & Telescope*, Nov. 1994, p. 30.

SELECTED READINGS FOR STUDENTS

Grades 4-6

Asimov, I. *Comets and Meteors.* 1990, Gareth Stevens.

Bendick, J. *Comets and Meteors: Visitors from Space.* 1991, Millbrook Press.

Couper, H. & Henbest, N. *Comets and Meteors.* 1987, Franklin Watts.

Darling, D. *Comets, Meteors, and Asteroids.* 1984, Dillon Press.

Simon, S. *Comets, Meteors, and Asteroids.* 1994, Morrow Junior Books. For even younger readers, but still useful.

Grades 7-9

David, L. "Celestial Slam Dunk: The Comet Crash of 1994" in *Odyssey*, Oct. 1994, p. 26. On the crash of Comet Shoemaker-Levy 9 into Jupiter.

Davis, D. & Yeomans, D. *Distant Planets.* 1989, Facts on File. Includes a section on comets.

Moskin, M. *Sky Dragons and Flaming Swords.* 1985, Walker. On comets in legend and history.

Schatz, D. *The Return of the Comet.* 1985, Pacific Science Center, (200 Second Ave., N., Seattle, WA 98109). A family guide to Halley's Comet with hands-on activities.

Vogt, G. *Halley's Comet: What We've Learned.* 1987, Franklin Watts.

SELECTED AUDIOVISUAL MATERIALS

Comet Halley Returns (29-min NASA video, 1986, from NASA CORE) Includes interview with astronomer Robert Chapman.

Comet Shoemaker-Levy 9 (set of 19 slides from Sky Publishing) Includes a booklet with captions by David Levy and others.

Dance of the Planets (IBM Software from many distributors) Helps simulate and display orbits of comets in the solar system.

Halley's Comet (sets of slides from Finley Holiday Films) They have a number of slide sets with this name; ask for their catalog.

RESOURCES FOR EXPLORING METEORS AND METEORITES

NOTE: Meteors are small pieces of cosmic dust and ice that burn up in the Earth's atmosphere; many are left over from the tracks of periodic comets. Meteorites are chunks of cosmic material that actually land on the Earth and can be analyzed in our laboratories.

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

On Meteors

Adams, F. "Observing Fallen Stars" in *Mercury*, Mar/Apr. 1980, p. 31.

- Bagnall, P. "Watching Halley's Debris" in *Astronomy*, May 1992, p. 78. On the two meteor showers caused by the famous comet.

Beatty, J. "Secret Impacts Revealed" in *Sky & Telescope*, Feb. 1994, p. 26. Military satellites have been tracking meteor explosions in the atmosphere for years, it turns out.

- Bone, N. *Meteors*. 1993, Sky Publishing. The definitive book on the subject, written for amateur observers.

Brophy, T. "Motes in the Solar System's Eye" in *Astronomy*, May 1993, p. 34.

- Burnham, R. "Catch a Cosmic Streaker" in *Astronomy*, Aug. 1991, p. 56. How to photograph meteors.

Kronk, G. "Meteor Showers" in *Mercury*, Nov/Dec. 1988, p. 162.

- MacRobert, A. "Meteor Observing" in *Sky & Telescope*, Aug. 1988, p. 131; Oct. 1988, p. 363.

Spratt, C. "It Came from Outer Space" in *Astronomy*, Feb. 1991, p. 64. On observing the fireballs that are the result of larger meteors.

On Meteorites

Chaikin, A. "A Stone's Throw from the Planets" in *Sky & Telescope*, Feb. 1983, p. 122. On meteorites from the Moon and Mars.

DiCicco, D. "New York's Cosmic Car Conker" in *Sky & Telescope*, Feb. 1993, p. 26. On the meteorite that hit a teenager's car.

- Dodd, R. *Thunderstones and Shooting Stars: The Meaning of Meteorites*. 1986, Harvard U. Press. A clear guide to the science of meteorites.

Hutchinson, R. *The Search for Our Beginnings*. 1983, Oxford U. Press. Focuses on how meteorites help us understand the history of our solar system.

McSween, H. *Meteorites and their Parent Planets*. 1987, Cambridge U. Press. A good general introduction by a geologist.

- Norton, O. *Rocks from Space*. 1994, Mountain Press Publishing (P.O. Box 2399, Missoula, MT 59806). A fine new guide for amateurs, with information on science, folklore, and collecting meteorites.

Spratt, C. & Stephens, S. "Against All Odds: Meteorites That Have Struck" in *Mercury*, Mar/Apr. 1992, p. 50. On rocks that have hit buildings, cars, etc.

SELECTED READINGS FOR STUDENTS

Grades 4-6

Asimov, I. *Comets and Meteors*. 1991, Gareth Stevens.

Couper, H. & Henbest, N. *Comets and Meteors*. 1987, Franklin Watts.

Darling, D. *Comets, Meteors, and Asteroids*. 1984, Dillon Press.

Simon, S. *Comets, Meteors, and Asteroids*. 1994, Morrow Junior Books.

Grades 7-9

Hutchinson, R. & Graham, A. *Meteorites*. 1993, Sterling. In the form of questions and answers, by two British minerologists.

Lauber, P. *Voyagers from Space: Meteors and Meteorites*. 1989, Thomas Crowell.

SELECTED AUDIOVISUAL MATERIALS

Meteorites (2 videotapes, 84 min total, made by Austrian TV in English, distributed by the Astronomical Society of the Pacific and others) Includes folklore, science, and impacts.

Meteorites (poster from Bethany Sciences, distributed by the Astronomical Society of the Pacific and others)

Meteorites (set of 55 slides from Science Graphics) Comprehensive introduction to what they look like, by O. Richard Norton.

Meteor Crater in Arizona

RESOURCES FOR EXPLORING COSMIC IMPACTS

by Andrew Fraknoi
Astronomical Society of the Pacific
390 Ashton Ave.
San Francisco, CA 94112

Books or articles marked with a • are especially useful for those just becoming familiar with the subject.

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

Books on Impacts and Collisions in General

• Chapman, C. & Morrison, D. *Cosmic Catastrophes.* 1989, Plenum Press. Excellent introduction to collision ideas, by two astronomers. [Good excerpts appeared in *Mercury* magazine, Nov/Dec. 1989, p. 185 and Jan/Feb. 1990, p. 18.]

Close, F. *End: Cosmic Catastrophe and the Fate of the Universe.* 1988, Simon & Schuster. By a physicist; has sections on impacts.

Erickson, J. *Target Earth: Asteroid Collisions Past and Future.* 1991, Tab Books. A geology writer's introduction.

Levy, D. *The Quest for Comets.* 1994, Plenum Press. Personal story of comet discovery and comet science by one of the discoverers of Shoemaker-Levy 9.

Sagan, C. *Pale Blue Dot.* 1994, Random House. Chapters 17 and 18 deal with impacts, Shoemaker-Levy 9, and political implications.

Good Introductory Articles on Impacts and Collisions in General

Begley, S. "The Science of Doom" in *Newsweek,* Nov. 23, 1992. A journalist's summary of some of the controversy.

Canavan, G. & Solem, J. "Interception of Near Earth Objects" in *Mercury,* Sep/Oct. 1992, p. 107. By defense researchers on options to prevent impacts.

Chyba, C. "The Cosmic Origins of Life on Earth" in *Astronomy* Nov. 1992, p. 28.

Cowen, R. "Rocky Relics: Getting the Lowdown on Near-Earth Asteroids" in *Science News,* Feb. 5, 1994, vol. 145, p. 88.

DiCicco, D. "New York's Cosmic Car Conker" in *Sky & Telescope,* Feb. 1993, p. 26. On a meteorite that hit a teenager's car.

Jaroff, L. "Look Out!" in *Time Magazine,* Feb. 1, 1993.

McFadden, L. & Chapman, C. "Near Earth Objects: Interplanetary Fugitives" in *Astronomy,* Aug. 1992, p. 30.

• Morrison, D. "The Spaceguard Survey: Protecting Earth from Cosmic Impacts" in *Mercury,* May/June 1992, p. 103.

Morrison, D. & Chapman, C. "Target Earth: It Will Happen" in *Sky & Telescope,* Mar. 1990, p. 261.

Sagan, C. & Ostro, S. "Long-range Consequences of Interplanetary Collisions" in *Issues in Science and Technology,* Summer 1994, vol. 10, no. 4, p. 67. Discussion of the risks in developing a weapons system to deflect asteroids that are coming our way.

Sinnott, R. "An Asteroid Whizzes Past the Earth" in *Sky & Telescope,* July 1989, p. 30.

Smith, F. "A Collision Over Collisions" in *Mercury*, May/June 1992, p. 97. Review of recent political and scientific debate about impacts and what to do about future ones.

Spratt, C. & Stephens, S. "Against All Odds: Meteorites that Have Struck Home" in *Mercury*, Mar/Apr. 1992, p. 50. Those that have struck buildings, animals, people, etc.

- Verschuur, G. "The End of Civilization: Asteroid Impacts" in *Astronomy*, Sep. 1991, p. 50.

Weissman, P. "Are Periodic Bombardments Real?" in *Sky & Telescope*, Mar. 1990, p. 266.

More Advanced Readings on Impacts and Collisions in General

Chapman, C. & Morrison, D. "Impacts on the Earth by Asteroids and Comets: Assessing the Hazard" in *Nature*, 6 Jan 1994, vol. 367, p. 33.

Gehrels, T., ed. *Hazards Due to Comets and Asteroids*. 1994, U. of Arizona Press. A technical conference volume, full of superb papers.

Grieve, R. "Impact Cratering on the Earth" in *Scientific American*, Apr. 1990, p. 66.

Articles on the 1908 Explosion in Siberia (The Tunguska Event)

Chaikin, A. "Target Tunguska" in *Sky & Telescope*, Jan. 1984, p. 18. Nice review, but now somewhat dated.

- Chyba, C. "Death from The Sky: Tunguska" in *Astronomy*, Dec. 1993, p. 38. Excellent review article.

Gallant, R. "Journey to Tunguska" in *Sky & Telescope*, June 1994, p. 38. A planetarium director tells of his trip to the site and fills in its history.

Peterson, I. "Tunguska: The Explosion of a Stony Asteroid" in *Science News*, Jan. 9, 1993, p. 23. A brief report on the new simulations by C. Chyba, et al.

Readings on the Impact that May Have Killed the Dinosaurs

Alvarez, W., et al. "What Caused the Mass Extinction: A Debate" in *Scientific American*, Oct. 1990, p. 76.

Beatty, J. "Killer Crater in the Yucatan?" in *Sky & Telescope*, July 1991, p. 38.

Dietz, R. "Demise of the Dinosaurs: Mystery Solved" in *Astronomy*, July 1991, p. 30. On the discovery of the crater in the Yucatan.

- Goldsmith, D. *Nemesis: The Death Star and Other Theories of Mass Extinctions*. 1985, Walker. A good skeptical book by an astronomer; a little dated now, but good for beginners.

Gould, S. "An Asteroid to Die For" in *Discover*, Oct. 1989, p. 60.

Articles on the Collision of Comet Shoemaker-Levy 9 with Jupiter

BEFORE THE IMPACTS

- Beatty, J. & Levy, D. "Awaiting the Crash" in *Sky & Telescope*, Jan. 1994, p. 40 and July 1994, p. 18. A good guide to preparations among scientists and observing hints for all of us; the July issue has a number of other stories about the collision as well.

Levy, D. "Pearls on a String" in *Sky & Telescope*, July 1993, p. 38. The story of the discovery, by the discoverer.

Reston, J. "Collision Course" in *Time Magazine*, May 23, 1994, p. 54. A nice overview, marred by a few (luckily small) factual errors.

- Sagan, C. "Comets on a Collision Course for Jupiter: A Warning for Us?" in *Parade Magazine*, June 5, 1994, p. 8. Superb overview.

AFTER THE IMPACTS

Beatty, J. & Goldman, S. "The Great Crash of 1994: A First Report" in *Sky & Telescope*, Oct. 1994, p. 18.

Benka, S. "In the Jupiter-Comet Clash of 1994, Astronomers are the Big Winners" in *Physics Today*, Feb. 1995, p. 17. A more technical summary of results.

Burnham, R. "Jupiter's Smash Hit" in *Astronomy*, Nov. 1994, p. 34.

Cowen, R. "Jovian Comet Crash: Puzzles and Insights" in *Science News*, Oct. 8, 1994; vol. 146, p. 229. Short report.

Eicher, D. "Death of a Comet" in *Astronomy*, Oct. 1994, p. 40.

O'Meara, S. "The Great Dark Spots of Jupiter" in *Sky & Telescope*, Nov. 1994, p. 30.

- Weissman, P. "Making Sense of Shoemaker-Levy 9" in *Astronomy*, May 1995, p. 48. Superb summary of what we learned and what we still don't know.

Technical reports on the collision appear in a special issue of *Science Magazine*, March 3, 1995.

SELECTED AUDIOVISUAL MATERIALS

Cosmic Catastrophes (a poster from Hansen Planetarium) Emphasizes mass extinctions and impacts.

The Impact Catastrophe that Ended the Mesozoic Era (software for the Mac from the Astronomical Society of the Pacific) Disc with paintings by astronomer/artist William Hartmann and information about the impact that killed the dinosaurs.

Meteorites (2 videotapes, 84 min total, produced by European TV and distributed by the Astronomical Society of the Pacific, among others) Includes folklore, science, impacts.

Terrestrial Impact Craters (set of 30 slides from Science Graphics) Views, diagrams, world map.

The Third Planet (an episode in *The Miracle Planet* TV series, from Ambrose Video or the Astronomical Society of the Pacific) Focus on the asteroid/comet collision hypothesis for the demise of the dinosaurs.

F

STAR-FINDING AND CONSTELLATIONS

ACTIVITIES INCLUDED IN STAR-FINDING AND CONSTELLATIONS

ACTIVITY	ESTIMATED GRADE LEVEL											
Grades	1	2	3	4	5	6	7	8	9	10	11	12
F-1. Looking Up: Observing the Nighttime Sky with the Unaided Eye This activity gives an overview of what to look for in the sky, and serves as a useful guide for an outdoor observing session.			▨	■	■	■	■	■	■	▨	▨	▨
F-2. Locating the Big Dipper Students make a device and use it to identify the Big Dipper and the North Star, and to learn how the Big Dipper's orientation in the sky changes during the year.			■	■	■	■	■	■	■	▨	▨	▨
F-3. Star Clocks Students construct a star-clock which connects the orientation of the Big Dipper in the sky with the time.				▨	■	■	■	■	■	▨	▨	▨
F-4. What's Your Latitude? Students make a device to measure the angular height of Polaris (as simulated in the classroom) and learn how navigators find their latitude on Earth.					■	■	■	■	■	▨	▨	▨
F-5. Star Finding with a Star Finder Students make a star chart to find constellations in the night sky at any time of the year.				■	■	■	■	■	■	▨	▨	▨
F-6. Star Frames Students make a transparent constellation map which makes it easy for them to locate a particular constellation in the night sky.			▨	■	■	■	▨	▨	▨	▨	▨	▨
F-7. Creating Constellations Students practice looking for patterns in a set of dots.			■	■	■	■						
F-8. Three-Dimensional Constellations Students create 3-D models of actual constellations, to see the differing distances of the stars from us and how the constellations would appear from other locations in space.			▨	■	■	■	■	▨	▨	▨		

■ - Grade levels recommended by authors ▨ - Can be extended to these grade levels.

About the Activities:
Star-Finding and Constellations

KEY IDEAS IN "STAR-FINDING AND CONSTELLATIONS"

- Stars and constellations offer a direct link between science and the humanities.
- Stars and constellations have practical uses such as navigation, as well as providing insight into the place of our home planet in the heavens.
- The *Benchmarks* recommends introducing the study of constellations at the 3-5 grade level, as preparation for learning about the planets and seasons.
- Many teachers prefer to start an astronomy unit with the study of stars and constellations.
- Constellations appear to be flat, but they are actually collections of stars scattered three-dimensionally through space.

The story of Orion and his hunting dogs, or of the Drinking Gourd, are as likely to be presented in an English or social studies classroom as in a science class. The stars have always provided a magnificent stage for the most important myths and legends of human cultures, from the Nile River to Chaco Canyon. But in addition, stars and constellations offer a direct link between science and the humanities. For example, the constellation Bootes, the Bear Driver, chases the Great Bear (Big Dipper) in a huge circle around the North Star, both as a dramatization of the myth, and as a consequence of the daily spinning of the Earth on its axis. Likewise, the origin of star names tells us about the many cultures whose heritage influences our lives today.

In addition to this important interdisciplinary connection, identifying constellations and stars makes it possible for students to figure out—through their own efforts—how people have applied their knowledge of the sky to such practical uses as navigation, as well as gaining insight into the place of our home planet in the heavens.

The *Benchmarks for Science Literacy* recommends introducing the study of constellations at the 3-5 grade level, as preparation for learning about the planets: "When students know that the star patterns stay the same as they move across the sky (and gradually shift with the seasons), they can then observe that the planets change their positions against the pattern of stars." (*Benchmarks*, page 62.) Also recommended is the study of constellations throughout the year, so that by the end of fifth grade, students are aware that "different stars can be seen in different seasons." (*Benchmarks*, page 63.) At the 6-8 level, students will be able to understand these seasonal changes in the constellations as a consequence of the Earth's yearly orbit around the Sun.

The constellation activities in this section could easily be done before the activities in the earlier sections. Many teachers prefer to start an astronomy unit with constellations even before discussing the scale of the solar system or planets. The various activities in this section move from observing star patterns, to observing movements of the constellations during the night and year, to using stars to find one's location on Earth. In the last activity, students find that constellations are not flat as they appear to be, but are rather collections of stars scattered three-dimensionally through space.

BACKGROUND:

STAR-FINDING AND CONSTELLATIONS

Throughout the centuries, people have looked to the stars to help them navigate across open oceans and featureless deserts, know when to plant and harvest, and preserve their myths and folklore. Ancient peoples used the appearance or disappearance of certain stars over the course of each year to mark the changing seasons. To make it easier to "read" this celestial calendar, they grouped the brighter stars into recognizable patterns or shapes, the constellations.

Today, astronomers officially recognize 88 constellations covering the entire sky, in the northern and southern hemispheres. Currently, 14 men and women, nine birds, two insects, 19 land animals, 10 water creatures, two centaurs, one head of hair, a serpent, a dragon, a flying horse, a river and 29 inanimate objects are represented in the night sky (the total comes to more than 88 because some constellations include more than one creature). It is important to realize that the great majority of star patterns bear little, if any, resemblance to the figures they are supposed to represent and whose name they bear. The ancient constellation-makers probably meant for them to be symbolic, not literal, representations of their favorite animals or fabled heroes, a kind of celestial "Hall of Fame."

Our modern constellation system comes to us from the ancient Greeks. The oldest description of the constellations as we know them comes from a poem, called *Phaenomena*, written about 270 B.C. by the Greek poet Aratus. However, it is clear from the poem that the constellations mentioned originated long before Aratus' time. No one is sure exactly where, when or by whom they were invented, but it is thought they originated with the ancient Babylonians and Sumerians. From there, the tradition of the constellations somehow made its way to Egypt, where early Greek scholars first heard about the constellations and wrote about them.

In 150 A.D., the Greek scientist Ptolemy published a book, known by its Arabic name, *The Almagest*, which contained a summary of Greek astronomical knowledge. The book included a catalog of 1022 stars, with estimates of their brightness, arranged into 48 constellations. These 48 formed the basis for our modern constellation system. Over the years, astronomers have added constellations to fill in the gaps between Ptolemy's figures and map the uncharted regions of the sky in the Southern Hemisphere.

At its first meeting in 1922, the International Astronomical Union (IAU), astronomy's worldwide governing body which is responsible, among other things, for assigning names to celestial objects, officially adopted the list of 88 constellations that we use today. Definitive boundaries between constellations, which extend out beyond the star figures, were set in 1930, so that every star, nebula, or galaxy, no matter how faint, now lies within the limits of one constellation. This means that, for today's astronomer, constellations refer not so much to the patterns of stars, but to precisely defined areas of the sky. When an astronomer says, "I observed a star in Orion last night," she doesn't necessarily mean that the star was part of the ancient sky pattern of Orion the Hunter, but merely that the star can be found in that sector of the sky which also contains Orion.

Nearly every culture on Earth has seen patterns in the stars. But, not surprisingly, very few have seen the same patterns. Take, for example, the Big Dipper, perhaps the most recognizable star pattern in the sky. The Big Dipper is not actually a constellation itself, but is part of a larger pattern known to the Greeks as Ursa Major, the Great Bear. The seven stars of the Big Dipper have inspired many stories, perhaps because they are bright and located so near the north celestial pole, the point around which the stars rotate during the course of a night. But not everyone calls it a Dipper. The British call it a Plough. In Southern France, it's a Saucepan. To the ancient Maya, it was a mythological parrot named Seven Macaw. The ancient Chinese thought of it as a special chariot for the Emperor of the Heavens or some other celestial bureaucrat. For the Micmac Indians of Canada's Maritime Provinces, along with several other North American Indian tribes, the bowl of the Big Dipper was a bear, and the stars in the handle represented hunters tracking the bear. And in the nineteenth century, the Big Dipper became a symbol of freedom for runaway slaves, who "followed the Drinking Gourd" to the northern states.

The ancient Greek tradition was to name stars by the position within a constellation. For example, Ptolemy refers to one star by the description, "the reddish one on the southern eye," a star we now know as Aldebaran in the constellation of Taurus the Bull. But these descriptions could get quite involved. Ptolemy refers to another star in the obsolete constellation of Argo the Boat as "the northernmost of two stars close together over the little shield in the poop," a bit cumbersome if you're trying to learn the names of many stars.

When Al-Sufi, one of the greatest Arabic astronomers, published his own version of Ptolemy's *Almagest* in the tenth century, he introduced many individual star names. For centuries, bedouin Arabs had given names to bright stars—for example, Aldebaran and Betelgeuse—since they regarded single stars as representing people and animals. Many of the original meanings of the names had been forgotten even in Al-Sufi's time, but some were direct translations of Ptolemy's descriptions. For example, the star name Fomalhaut (in the constellation of Pisces) comes from the Arabic for "mouth of the southern fish," which is how Ptolemy described it in *The Almagest.*

After the tenth century, the works of Ptolemy and others were re-introduced into Europe by the Islamic Arabs, and the Greek books were translated from Arabic into Latin, the scientific language of the day. Thus we know Ptolemy's work from its Arabic translation, *The Almagest*, not by its original Greek title. And it explains why we have a system of Greek constellations with Latin titles containing stars with Arabic names.

With few exceptions, the stars in a constellation have no connection with one another. They are actually at very different distances from the Sun. Chance alignments of stars have created the patterns we see in the sky. These alignments are not permanent, however. The patterns the stars form look much the same today as they did when the constellations were first named nearly 3000 years ago. Indeed, the stars seem almost "fixed" in place. But the stars are all moving relative to the Sun and each other, most with speeds of many kilometers per second. Because they are so very far away, it will take thousands of lifetimes to see significant changes in the star patterns. But, over time, they will change. As a result of the motions of the stars within it, for example, the handle of the Big Dipper will, in about 50,000 years, appear significantly more bent than it is today. We will, no doubt, keep the same names for the constellations, even if the stars change their positions. Constellations are, after all, products of human imagination, not nature.

LOOKING UP: OBSERVING THE NIGHTTIME SKY WITH THE UNAIDED EYE

ACTIVITY F-1

GRADE LEVEL: 4-9

Source: Reprinted by permission from *Project Pulsar*, St. Louis Science Center, 5050 Oakland Avenue, St. Louis, MO 63110. Publication is no longer in print.

What's This Activity About?

This is a wonderful activity overview for an outdoor evening observing session or "star party." Even without telescopes, there are many things for students to observe, including levels of light pollution, colors of stars, and possibly extended nebulae of gas, dust, or large concentrations of stars (if the skies are dark and clear).

What Will Students Do?

Students look for particular stars and their characteristic colors and brightnesses. Depending on how dark the skies are, students also look for star clusters. Students also compare the relative brightness of the sky near towns to gauge the levels of light pollution.

Tips and Suggestions

- Consider handing this out in advance as a guide for an evening star party with your students and their families.
- Plan a star party as a central or culminating activity to your astronomy unit, and invite families or other classes.
- Contact your local astronomy club to help with your star party by bringing telescopes. You can find astronomy clubs by calling a local planetarium, college astronomy department, or looking in the September issue of *Sky & Telescope* magazine.
- Star parties with classes of students work better when they are structured. This activity provides students with structured observing activities.
- See the reading list in this section of the notebook for a wide range of references on star and constellation identification.
- An especially helpful tool for learning the bright stars and constellations for each season is a set of audiotapes called *Tapes of the Night Sky*, from the Astronomical Society of the Pacific.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
The eye's sensitivity Light pollution Rotation of the Earth	Observing Systematically	Scale Patterns of Change

LOOKING UP:

OBSERVING THE NIGHTTIME SKY WITH THE UNAIDED EYE

INTRODUCTION

An outdoor observing session is not the kind of activity that can be easily structured into a 1–2–3–4 sequence of specific actions. It should, instead, be a time for free student discovery. It can also be a tremendous source of questions to be looked up by the students later, in the classroom. Then, as a follow–up activity, they can re-explore the skies with new awareness at a second outdoor meeting. It is recommended that the teacher and/or other adult supervisors going with the students to the night observing sessions brief themselves by at least reading the background information given below.

MATERIALS NEEDED

The night sky on a relatively clear night. An observing site dark enough to see more than just the brightest stars. Star charts or hand–drawn star maps prepared before the observing session by the students. Flashlights. Some areas may require some sort of ground covering tarp or plastic for comfortable observing. An unobstructed view of the sky.

PROCEDURE

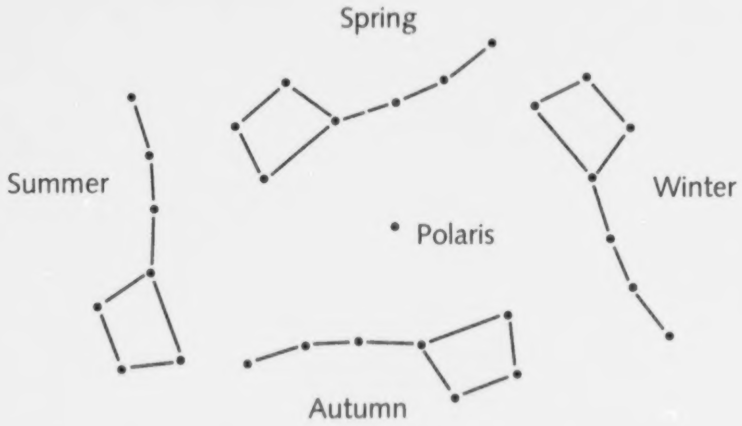
After lying down flat on your back on some sort of ground cover, with a clear view of the sky, look up. Take just a few moments, 3 to 5 minutes to appreciate all that you are seeing. Are all the stars the same brightness? Are they all the same color? How are they arranged? Can you pick out any star pictures or constellations? Can you make up some constellations of your own? Open your eyes and really *see* the sky.

Once you have "tuned in" to the sky above, it soon becomes apparent that some form of organization needs to be imposed on the skies to help make sense of what you see; to aid you in describing what you see and for telling others where you are looking.

The first way of organizing the sky is by using the four basic directions: North, South, East, and West. How can you find the directions? Some might use a compass. If you do not have one, however, are you out of luck? No! Familiar landmarks can also serve as direction indicators. But, what if you are on vacation in an unfamiliar locale? Never fear, for the skies can show direction, too. Each day a giant direction marker rises in the East in the morning, and slowly sets in the West each evening—the Sun can show three directions directly and North is inferred. Yet, even if you do not use the Sun, you can turn to the nighttime sky to use the stars as direction signposts.

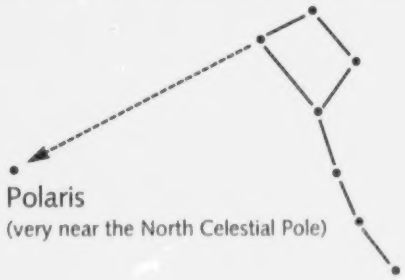
For thousands of years, people on Earth have tried to find ways to use the beautiful stars above. There is at least one way that we today can use the skill of the ancients. On any clear night, we can find the constellation known to astronomers as Ursa Major, meaning the Great Bear, or more familiarly, the Big

Dipper. From places like St. Louis (in the U.S.), this conspicuous group of seven stars can be seen to the North in the approximate positions shown below:



(**Note:** All sightings are shown for roughly 9 p.m.)

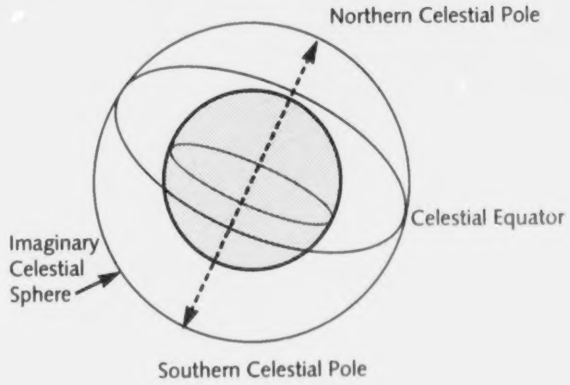
Once the Big Dipper has been found, look specifically at the two end stars in the bowl or cup of the Dipper. Together these stars are called the Pointers. They have this title because an imaginary line drawn through them and stretched out across the sky will soon reach a fairly bright but unspectacular star. This star is Polaris, the North Star, and it marks our northern direction. When you stand facing Polaris, you are looking due North.



Polaris has this name because of its unique position in the sky. Coincidentally, the northern end of Earth's imaginary axis points toward the region of space very near to the North Star. The North Pole of the sky is called the North Celestial Pole by astronomers.

NOTE:

Many people in your community probably enjoy astronomy as a hobby. It always pays to ask around to find someone who could help with the observing session.



For this reason, as Earth rotates or turns on its axis once each day, all the stars except Polaris seem to move with time. Most appear to rise in the East and set in the West just as the Sun does each day. Other stars, very near Polaris and called circumpolar, never dip below the horizon and so continually circle the North Celestial Pole day in and day out. Only Polaris, since it is so close to the pole, never appears to move.

Once the Big Dipper has been successfully used to locate Polaris and the North direction, South, East and West can be derived. As you face North, East will be on your right hand side, West on your left and South directly behind you.

The Big Dipper and Polaris can also be used as signposts to other star groups or constellations. For example, in the Spring and Summer skies the arc of the handle of the Big Dipper can be extended out away from the Dipper to reach the bright star Arcturus in the constellation of Boötes, the Herdsman. You can "arc to Arcturus." This "leap–frogging" between constellations can be a very effective way of learning the skies.

ADDITIONAL ACTIVITIES

As mentioned in the opening of this activity, students really looking at the sky for the first time will begin to see many things they never noticed before. Any or all of these "revelations" can serve as topics for individual or class investigation. Some topics which might arise are listed below.

1. What are the stories or myths behind the constellation figures?
2. Why are some stars brighter than others? (Not all stars are at

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the same distance from us, so near ones are brighter than ones farther away—just like nearby street lights look brighter than distant ones. Also, some stars are intrinsically brighter than others.)

3. Why do the stars twinkle? (The twinkling effect is the result of the fragile beams of starlight being bounced about by the moving layers of Earth's atmosphere.)
4. Some students might be surprised to see a "Shooting" or "Falling Star." They are really not stars at all but small sand–sized bits of planetary dust falling through our atmosphere. As they fall, they are heated to glowing by the friction of hitting against air particles.
5. Why are the stars different colors? (Stars are different colors because of differences in their surface temperature. Hot stars are blue or white while cooler stars are red or orange.)

GENERAL OBSERVING HINTS

- It takes your eyes up to 45 minutes to become completely adjusted to the dark, so, do not try to see very faint objects just after stepping outside.
- Observe from an area as free from light as possible, though some useful observing can be done just about anywhere except right under the street light! Also, have as wide a field of view as possible. Do not observe from under a tree.
- After your eyes are night adapted, only dim red light will not disrupt it. So, to see to walk or read your star chart, cover a flashlight with a red balloon or shine the light through your fingers to use your blood vessels to color the light red. Some teachers buy red cellophane and distribute squares of it and rubber bands to hold them on the flashlight.
- Find your directions first. Then, use constellations you know to "leap–frog" to new ones. Plan your "leaps" first by using a star chart.
- To observe faint objects, do not look straight at them. Rather, look at them out of the corner of your eye. The edges of your retina (the part of the eye that gathers in light) are much more sensitive to dim light. Direct your eyes at a point just off to the right or left of a faint object in order to use this peripheral vision.

LOCATING THE BIG DIPPER

ACTIVITY F-2

GRADE LEVEL: 3-9

Source: Reprinted by permission from *Under Roof, Dome & Sky*, Revised Second Edition. Copyright ©1980, Revised 1992 by the Middle Atlantic Planetarium Society. M.A.P.S. c/o Francine Jackson, Educational Committee Chair, P.O. Box 353, Providence, RI 02901. Cost: M.A.P.S. members: $15.00; Non members: $25.00

What's This Activity About?

Once students can identify at least one constellation in the sky, their confidence with nighttime observing increases dramatically. Perhaps the easiest constellation to find in the northern hemisphere is Ursa Major, with its familiar seven-starred pattern, the Big Dipper. The Dipper is visible year round (although it is low against the northern horizon in late autumn and early winter after sunset), and its two pointer stars, Dubhe and Merak, can be used to locate Polaris, the North Star.

This activity will help students identify the Dipper and the North Star easily, with a simple all-year clock. It also calls attention to the changing position of constellations about the North Star during the evening and over a year.

What Will Students Do?

Students create a Dipper-Finder clock and use it to match the orientation of the Big Dipper to the season and time. The Dipper-Finder shows only the Dipper and the North Star to help students easily find the constellation.

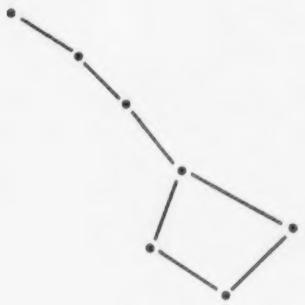
Tips and Suggestions

- The Dipper-Finder is not intended to replace a more complete star chart. In the next activity in this section, "Star Clocks," students create a more realistic, detailed map of the northern stars.
- Give serious consideration to starting all students out with the Dipper-Finder first, especially if they have not had much experience observing the evening skies.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Rotation of the sky about the North Star Earth's daily rotational motion Earth's annual revolution about the Sun	Observing Systematically Comparing	Patterns of Change

LOCATING THE BIG DIPPER



OBJECTIVES

1) The student will be able to use the Dipper finder to locate the position of the Big Dipper at selected hours and months of the year.

2) The students will be able to locate the North Star (Polaris).

Children will start feeling at home with the stars and will become interested in observing them further when they realize that they can easily find the Big Dipper on a clear night. The Big Dipper, in turn, will help them locate a very important star for finding their way, Polaris. The Dipper finder to be made in this activity will tell them in what general region of the northern sky to look for the Big Dipper at any hour of the night throughout the year. As they use it, they will see how the Dipper appears to move around the Pole Star.

STUDENT PREPARATION

GRADE LEVEL

Elementary

CONTENT BACKGROUND

Some familiarity with Big Dipper and its shape; understanding of the Earth's rotation.

FACTS AND CONCEPTS

- The Big Dipper appears to move in the sky from hour to hour.
- The Big Dipper appears to change its position from month to month.
- The pointer stars in the Big Dipper point toward the North Star (Polaris).

MATERIALS

Pattern for Dipper finder and accompanying directions for constructing and using it (see Dipper finder pattern at end of activity), brad, rubber cement, scissors.

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PROCEDURES

1. Review rotation of the Earth, shape of Big Dipper and the usefulness of this star configuration in finding the North Star and the directions north, east, south, and west.

2. Ask students to construct the Dipper finder, using the materials given to them.

3. Let students practice setting and orienting the Dipper finder for various dates and hours of night until they become familiar with its operation.

FOLLOW-UP ACTIVITIES

1. Each student should take his or her Dipper finder home and use it to locate the Dipper and North Star in the night sky.

2. The Dipper finder is large enough to include more stars. Ask students to plot the Little Dipper, Cassiopeia, and Draco on their Dipper finders from the sky at night. On the next school day, they should check their success with a star chart.

3. At upper elementary levels, guide students in using their Dipper finders and the Big Dipper to tell the time of night.

EVALUATION SUGGESTIONS

Evaluate student performance in the follow-up activities, and the understanding they exhibit in using the Dipper finder.

NOTE:

For Dipper finder pattern used in the activity, see following page.

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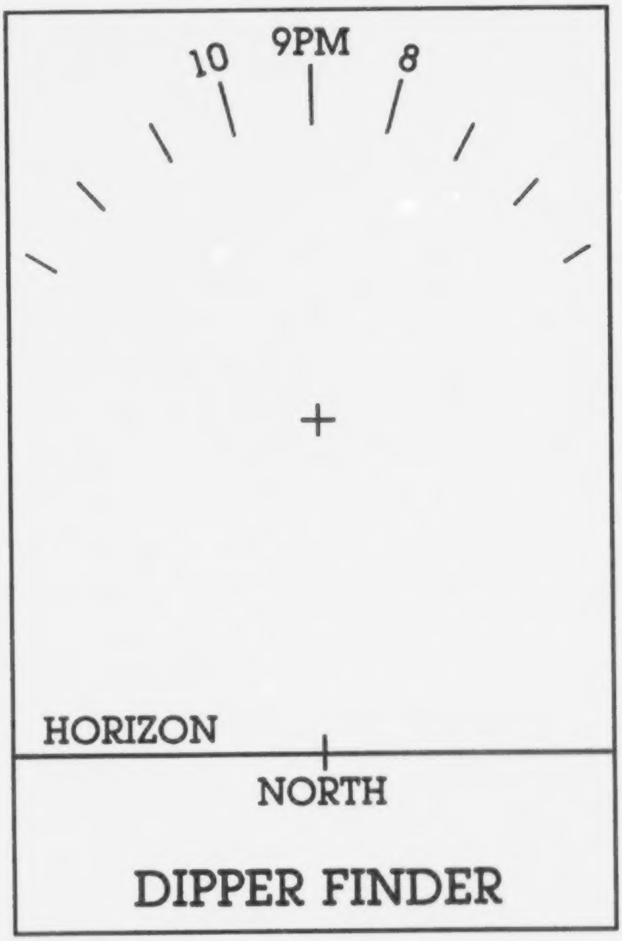
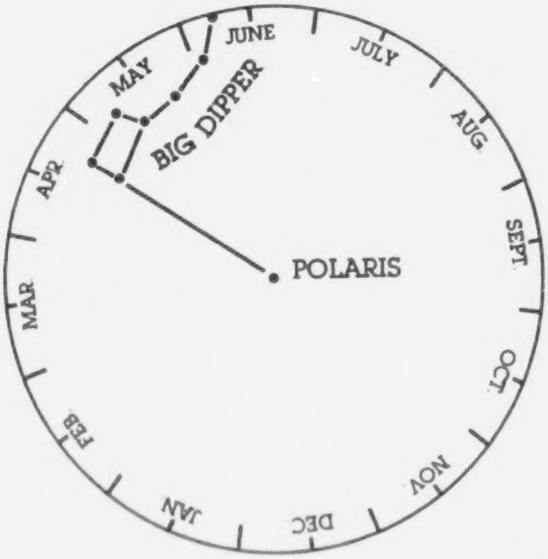

10
9PM
8
HORIZON
NORTH
DIPPER FINDER


JUNE
JULY
AUG
SEPT.
OCT.
NOV.
DEC
JAN
FEB
MAR
APR
MAY
BIG DIPPER
POLARIS

This Dipper Finder will show you the correct position of the Big Dipper at any hour for any month throughout the year.

1. Cut out the circle and rectangle.
2. Place the circle on top of the rectangle and fasten with a brad through the North Star (Polaris).
3. Set the month to the correct time and then go outside and find the Big Dipper

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STAR CLOCKS

ACTIVITY F-3

GRADE LEVEL: 5-9+

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What's This Activity About?

Before humans had watches with luminous dials or digital clocks, people used the stars to tell the time at night. This activity will teach students how the Big Dipper can be used as a clock to tell the approximate local time.

What Will Students Do?

Students construct a northern-hemisphere star clock and learn to set the clock based on the position of the Big Dipper. Students use the position of the Big Dipper to tell the time. They also can predict where the Big Dipper will be at a given time and month.

Tips and Suggestions

This activity describes using a Star Finder which students make in the activity "Star Finding with a Star Finder" in this section. This activity can be done quite successfully before students create the more elaborate Star Finder.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Motions of the northern constellations	Observing	Patterns of Change
Rotation of the Earth	Predicting	Models

STAR CLOCKS

Our daylight concept of time is based on the motion and position of the sun. In this activity students are challenged to tell time at night with a star clock. They will determine the correct orientation needed for the star clock to function. Keeping track of the positions of constellations with the star clock helps students visually understand the relationship between the constellations' changing positions and our concept of passing time.

CONCEPT

The motion and position of constellations can be used to tell time.

OBJECTIVES

Students will:

- construct star clocks.
- determine local time using a star clock.
- make observations about the passing of time using their star clocks.
- explain the relationship between the motion of the stars and our concept of time.

MATERIALS

Star Clock pattern
Star Finder from Activity Two
large cardboard model of constellations of the star clock (optional)
paper fastener
scissors
glue

PROCEDURE

Advanced Preparation:
Make copies of the Star Clock pattern for each student. You may wish to create a large classroom version of the constellation section of the star clock to use as a teaching tool.

1. Ask students to tell you the time. Have them explain how they got that information. Ask how people long ago might have told time. What instruments could they use? (Take suggestions: for example, using the stars, using the sun, dripping water, or pouring sand.)

2. Ask students to describe how a person might tell time at night before watches and clocks were invented. Try to steer their discussion toward including ideas about stars and changing star positions.

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3. Have students take out their star finders. Ask them to set their star finders for the position of the stars at 10:00 p.m. tonight, using the simple constellation field. Allow time for them to observe the position of the stars and constellations. Reset the star finder for 4:00 a.m. Ask students to describe the constellation differences they notice between these two settings. Discuss their observations and conclusions that stars are found in different positions at different times. (This is due to the daily rotation of the earth.)

4. Distribute copies of the Star Clock pattern and paper fasteners. Have students cut out the pieces and assemble their star clocks by putting the disk with the words "The Time Is" on top of the disk with the months. A paper fastener through the center of both disks holds them together.

5. Refer students back to their star finder, remind them that the positions of stars are different at different times. Explain to them that the star clock is a simplified star finder that can be used to tell time at night.

6. To use a star clock have students face the northern night sky, holding the star clock so the current month is at the top of the circle. They should turn the black disk until the outline of the Big Dipper lines up with the Big Dipper's position in the sky. (A large version of the black disk can help students practice accurately aligning the constellations of their clocks.) Ask students to tell the time by reading their star clocks.
   Teacher's Note: If it is daylight savings time students need to add one hour to their star clock reading.

7. To practice using the star clock, have each student select a time to leave on a trip to the Andromeda Galaxy and set their clocks. Carefully observe the position of the constellations; then, using the large classroom model, rotate the model. When the model matches the positions each of the students have selected on their star clocks, they should each make a ringing sound like an alarm clock. Since students have selected different times, be prepared for alarm clock sounds at different times.

8. The star clock can be used two different ways. It can use the position of the stars to tell what time of night it is, or it can tell what position the Big Dipper will be in at a specific time, which may make it easier to find in the night sky. Remind the students that they must always be facing the North Star when using the star clock. Challenge them to try to use their clocks tonight at home.

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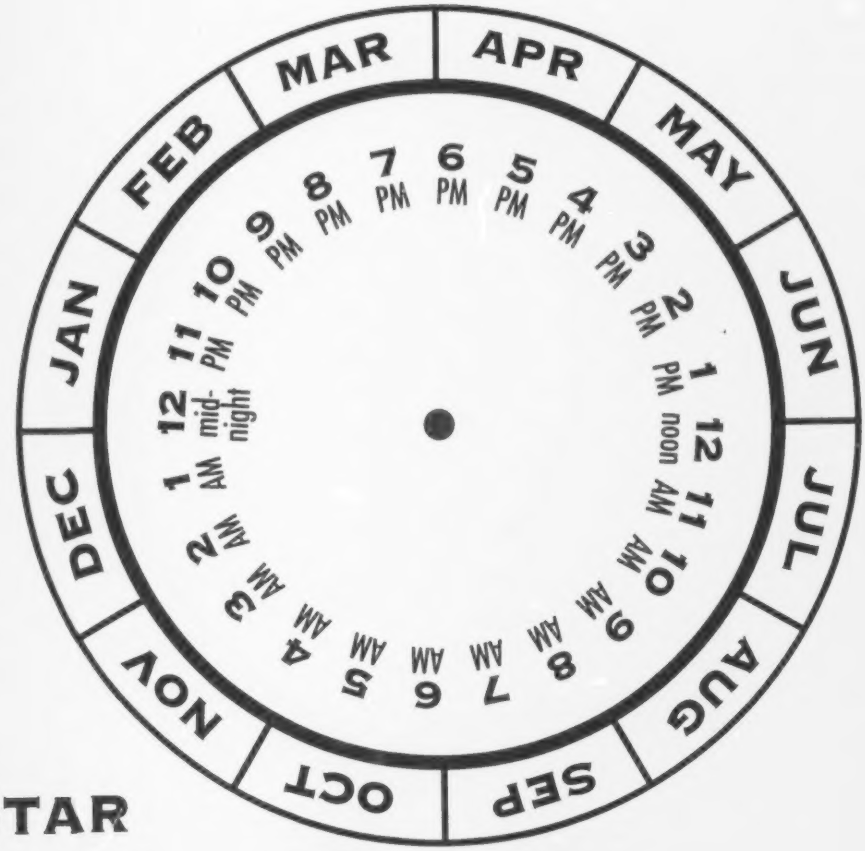
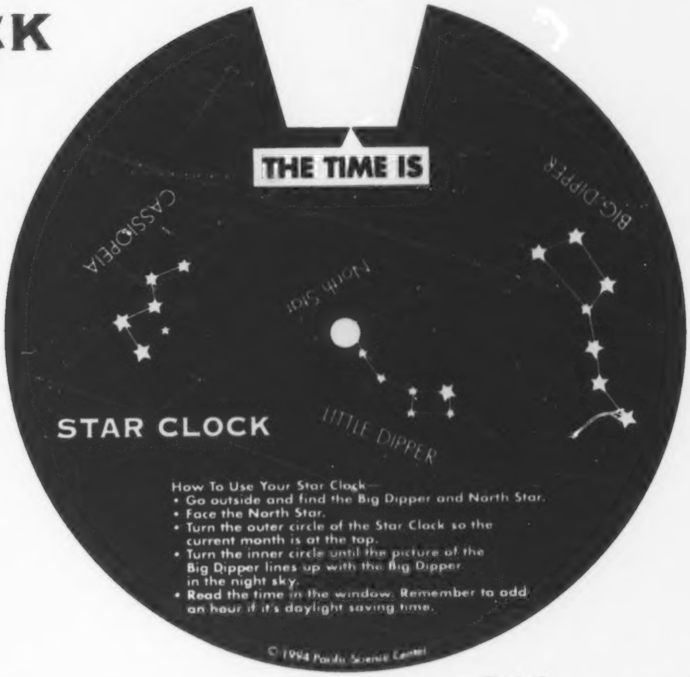

JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
12 mid-night
11 PM
10 PM
9 PM
8 PM
7 PM
6 PM
5 PM
4 PM
3 PM
2 PM
1 PM
12 noon
11 AM
10 AM
9 AM
8 AM
7 AM
6 AM
5 AM
4 AM
3 AM
2 AM
1 AM

STAR CLOCK


THE TIME IS
CASSIOPEIA
North Star
BIG DIPPER
LITTLE DIPPER
STAR CLOCK

How To Use Your Star Clock—
- Go outside and find the Big Dipper and North Star.
- Face the North Star.
- Turn the outer circle of the Star Clock so the current month is at the top.
- Turn the inner circle until the picture of the Big Dipper lines up with the Big Dipper in the night sky.
- Read the time in the window. Remember to add an hour if it's daylight saving time.

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WHAT'S YOUR LATITUDE?

ACTIVITY F-4

GRADE LEVEL: 4-9+

Source: Reprinted by permission from PASS (Planetarium Activities for Student Success), Vol.10 *Who "Discovered" America?* Produced by the Astronomy Education Program of the Lawrence Hall of Science, University of California, Berkeley. ©1992 by The Regents of the University of California. Available through the *Eureka!* catalog, Lawrence Hall of Science, University of California, Berkeley, CA 94720-5200; (510) 642-1016.

What's This Activity About?

The strength of this activity comes from its focus on the height of Polaris over the northern horizon, and its correlation with the observer's latitude. This fact, perhaps more than any other, was critical for navigation by peoples around the Northern Hemishpere. The activity includes some excellent questions that you can use to prompt and challenge students.

What Will Students Do?

Students make a quadrant and use it to measure the altitude angle of the North Star, projected at different positions around the room to simulate different positions in the sky.

Tips and Suggestions

- This activity works best in a planetarium, but it is still useful in a regular classroom.
- If you do not have access to a planetarium, spend some time with your students simulating the height of Polaris as seen at different latitudes. Have an Earth globe handy to ask leading questions about what someone might see from different places on Earth.
- The activity can be tied into geography, social studies, and history.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Earth's spherical shape	Observing	Models and Simulations
Earth's rotation about its axis	Visualizing	
The orientation of Earth in space	Reasoning	

What's Your Latitude?

One of the most important tasks of a navigator is to determine where she is at all times. The height of the North Star above the horizon is affected by where you are on the Earth. The altitude angle of the North Star is a very good approximation (within 1° or better) for your latitude on Earth. In this activity, your students review how to find the Big Dipper and the North Star. Then they build a quadrant and practice using it to tell latitude.

Part A — Finding the North Star

Before the Lesson

Using an overhead projector to show stars creates a very nice "planetarium effect." Following are instructions to make a simple star frame for the constellations needed in this program.

Materials for a Star Projector

- ☐ 1 copy of star pattern, page 47
- ☐ 1 piece of aluminum foil large enough to cover the star pattern copy
- ☐ 1 piece of corrugated cardboard to protect surface of table or desk
- ☐ 1 pushpin and a sharp pencil
- ☐ 1 file folder or tag board to make a frame
- ☐ 1 roll of transparent tape
- ☐ 1 yellow paper star of your design to mark the position of the North Star on the wall
- ☐ 1 overhead projector

1. Make star holes in the aluminum foil.

a. Place the paper copy of the star pattern on top of the aluminum foil and the cardboard.

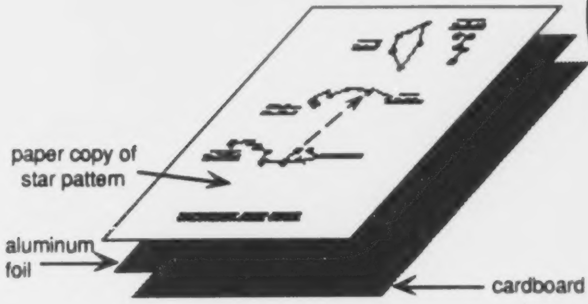
b. Use the pushpin to poke a hole through the paper and the aluminum foil for each star.

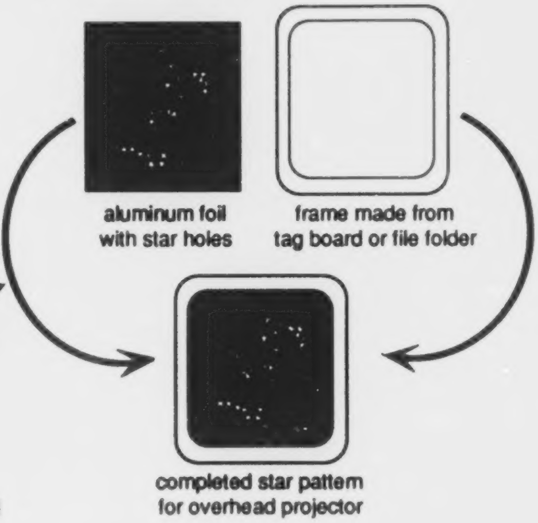
c. Remove the paper copy, and use the pencil to slightly enlarge the stars of the Big Dipper and the Polaris, the North Star. The larger the hole, the brighter the star appears.

d. Test the aluminum foil star pattern on your overhead projector.

2. Make a frame for the foil.

a. Make a frame for the aluminum foil from a file folder or tag board so that the entire surface of your overhead projector is covered by the framed star pattern.




aluminum foil with star holes
frame made from tag board or file folder
completed star pattern for overhead projector

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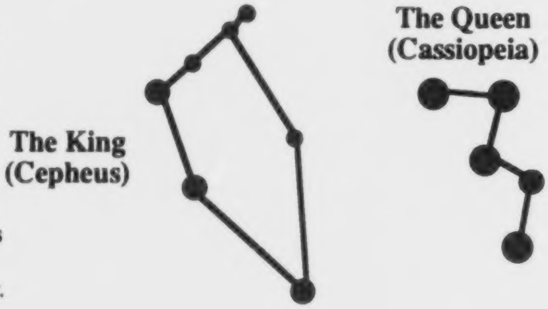
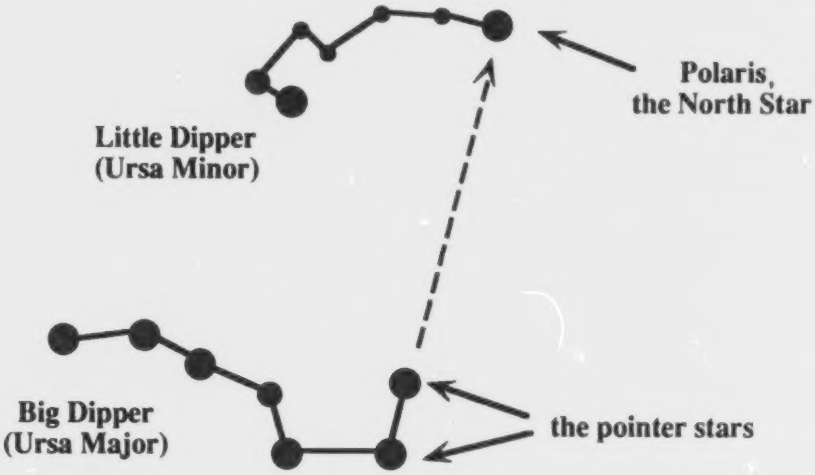
b. Mark the front side of the star pattern so that when you use it during the presentation, the star patterns are correct. If the frame is flipped over front-to-back, all of the star patterns will appear backwards.

Star Pattern for Projecting Stars in the Classroom: Use this pattern to make the framed aluminum foil star pattern, and use this diagram as a reference to teach your students the northern constellations that surround Polaris, the North Star.





In Class

Set up the overhead projector using the star pattern frame. Ask your students the following questions. Encourage the students to use the star projector in their explanations as well. You can supplement their answers as well. Sample answers are given after each question.

1. What is the North Star?

The North Star, Polaris, is used as a navigational star in *Who "Discovered" America?* and by real-life navigators for finding true north. All of the other stars appear to circle around the North Star once every 24 hours.

2. How can you find the North Star in the sky?

First find the Big Dipper (also called Ursa Major, the Big Bear.) The two front stars in the bowl of the Big Dipper point to the North Star. You can then find the much fainter Little Dipper (also called Ursa Minor, the little Bear), since the North Star is the end of the handle of the Little Dipper.

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3. Why does the North Star seem to stay in one place?

As the Earth spins rotates. on its axis, the Sun, Moon, planets, and stars appear to rise and set, creating the cycle of day and night. The North Pole of the Earth points toward the same place in space throughout the year. We call the place in space where the Earth's North Pole points the ***north celestial pole***. The North Star is within 1° of the ***north celestial pole***, and we call it *Polaris* which means "pole star."

Part B. Make a Quadrant

A quadrant is a quarter of a circle. It is also the name of an instrument, shaped like a quarter of a circle, used by navigators in Columbus's day to determine latitude—how far north or south of the equator the navigator was located.

Materials for Making Quadrants

- ☐ 1 copy of "'Do-It-Yourself' Quadrant" for each student (master on page 6)
- ☐ push pins, one per student quadrant
- ☐ pencil eraser tip, small piece of cork or soft wood, one per student
- ☐ cardboard or file folder, 20 x 21.5 cm (8" x 8.5"), one per student
- ☐ glue stick, one for every two students
- ☐ scissors, one for every two students

In Class

Instructions for making and testing a Do-It-Yourself Quadrant

1. Have the students glue the quadrant sheet to the cardboard and cut it out.
2. Demonstrate how to assemble the quadrant according to the directions printed on the student copy of each quadrant. Have the students assemble their quadrants.
3. When assembled, check the pointer on each student's quadrant: it should swing freely.
4. To measure the altitude or height or an object, look along the top edge of the quadrant, aligning the back and front of that edge with the object. Wait until the pointer stops swinging.
5. Pinch the pointer against the scale; then read the angle from the quadrant.

To insure that students know how to use their quadrants correctly, take your students outside and measure the height of the school flag pole or a tall building from a distance. If the students stand close together, or in a line, their angular measurements should be very close to the same number. Any student who has a measurement more than 10° from the average probably needs some help in holding and sighting the quadrant correctly.

Emphasize that quadrants measure the altitude in ***degrees***. They do not measure directly the distance of something above the ground.

Demonstrate this by having your students measure the altitude angle of a distant object, like the top of a flag pole, and then go about half of the distance towards the object and measure it again. ***Is the altitude angle higher or lower? (Higher.)*** As they get closer and closer to the pole, the angle will get higher and higher, up to the limit of 90°. When they stand right next to the flag pole, and look up at the top, they will measure very nearly 90°. When they measure an object at eye level, such as the horizon, they will measure 0°.

Although the quadrant does not measure distance directly, you can calculate the distance above the ground if you know your distance from the object and use geometry or trigonometry.

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Part C. Measuring the Altitude Angle of the North Star

1. Using the North Star overhead projector setup, challenge the students to measure the altitude angle of the North Star with their quadrants.

2. Switch off the overhead projector and tilt the projection lens so that the North Star will appear higher on the wall. Have students measure the altitude angle again. Ask, ***"Has the altitude angle increased or decreased?"*** *(Increased.)* ***"Would this mean that we are further north or further south on the Earth?"*** *(Further north.)*

3. Repeat step 2, but adjust the North Star lower than its first position.

4. How does my place on Earth affect where I see the North Star?

If you were to stand on the North Pole of the Earth, you would see the North Star at the zenith. As you walk south from the North Pole the only way to go!, you would see the North Star at a lower and lower altitude. By the time you trek to the equator, the North Star is on your horizon at an altitude of 0°—the same as the latitude of the equator. Below the equator you would not see the North Star at all. Unfortunately, there is no South Star, since the Earth's south pole does not point to a visible star. South of the equator, navigators used other strs or the sun, and had to make more complicated calculations.

The North Star makes a very small circle around the north celestial pole. Serious navigators have to make adjustments for this, but the North Star seems to stay in one place for the ordinary stargazer.

Going Further

1. Geography Game

Using a large world map or globe, explain that latitude is the number of degrees north or south of the equator that a place is located. Its longitude is the number of degrees east or west it is of the prime meridian. The ***prime meridian*** is a north-south line that runs through Greenwich England.

a. Each team of 2 students picks a secret geographic location on a world map or globe that has latitude and longitude marked.

b. They write down on a piece of paper the word *Polaris*, their names, and the longitude of their secret place.

c. Each team labels a particular chair with a second piece of paper with their names on it

d. Using a quadrant, viewing from that chair, they find a particular spot on a wall which is the altitude angle that Polaris would be from their secret geographic place. This will require some trial and error to accomplish.

f. They tape their Polaris paper from step 2 to that spot on the wall.

g. Teams challenge each other to figure out their secret places by reading the longitude on the Polaris paper on the wall, and using a quadrant to determine the latitude by measuring the altitude angle of Polaris as viewed from the designated chair. It is important that chairs not be moved.

2. What's Your Latitude at Home?

When your students have learned to locate the North Star from the activities in *"Who "Discovered" America?* they can take their quadrants home, and measure the altitude of the North Star in the real night sky. Their measurement will vary ± 5°, but the class average will probably be close to the latitude of your school. You may obtain your latitude from a local airport, an atlas, your city planning office, or a United States Geological Survey map at the local library. The GEMS Teacher's Guide, *Height-O-Meters*, published by Lawrence Hall of Science, offers additional lessons focused on angular measurement for grades 6–10.

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Background for Teachers:

Why Does the Height of the North Star Tell Us Our Latitude?

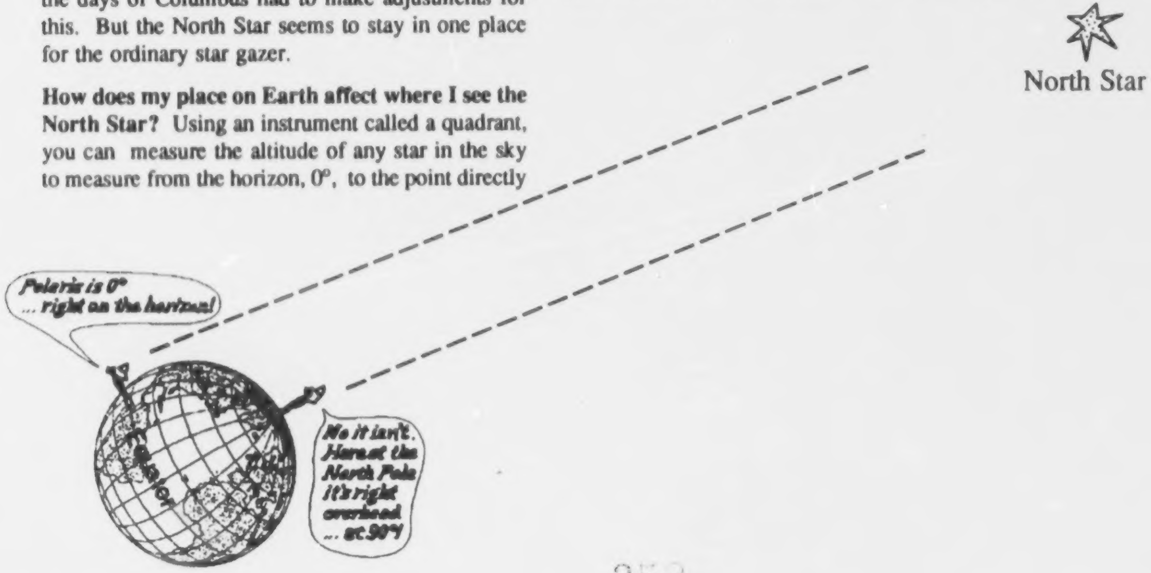
What is the North Star? The North Star, Polaris, is used as a navigational star in *Who "Discovered" America?* Real-life navigators use it for finding true north. All of the other stars appear to circle around the North Star once every 24 hours.

Where is the North Star in the sky? First find the Big Dipper. It is also called Ursa Major, the Big Bear. The two front stars in the bowl of the Big Dipper point to the North Star. You can then find the much fainter Little Dipper. It is also called Ursa Minor, the little Bear. The North Star is the end of the handle of the Little Dipper.

Why does the North Star seem to stay in one place? As the Earth spins (rotates) on its axis, the Sun, Moon, planets and stars appear to rise and set. This creates the cycle of day and night. The North Pole and South Pole of the Earth point toward the same place in space throughout the year. We call the place in space where the Earth's North Pole points *the north celestial pole*. The Earth's South Pole points toward the *south celestial pole*. The North Star is within 1° of the *north celestial pole*. We call that star *Polaris* which means "pole star." The North Star makes a very small circle around the north celestial pole. Serious navigators in the days of Columbus had to make adjustments for this. But the North Star seems to stay in one place for the ordinary star gazer.

How does my place on Earth affect where I see the North Star? Using an instrument called a quadrant, you can measure the altitude of any star in the sky to measure from the horizon, 0°, to the point directly overhead, 90°. The point in the sky directly over each observer's head is called the *zenith*. Your students can easily make one from a copy of the master on page 6. A star halfway between the horizon and the point directly overhead would have an altitude of 45°. If you were to stand on the North Pole of the Earth, you would see the North Star at your zenith. As you walk south from the North Pole (the only way to go!), you would see the North Star at a lower and lower altitude. By the time you trek to the equator, the North Star is on your horizon at an altitude of 0°. This is the same as the latitude of the equator. Below the equator you would not see the North Star at all. Unfortunately, there is no South Star, since the Earth's South Pole does not point to a visible star.

How does the North Star help you to navigate? One of the most important tasks of navigators is to determine where they are at all times. As mentioned above, the height of the North Star above the horizon is affected by where you are on the Earth. In fact, the altitude of the North Star is a very good approximation for your latitude on Earth. If you measure the North Star's altitude to be 90° then you must be at the North Pole. If you measure the North Star's altitude to be 0°, you must be at the equator.


North Star
Polaris is 0° ... right on the horizon!
No it isn't. Here at the North Pole it's right overhead ... at 90°!

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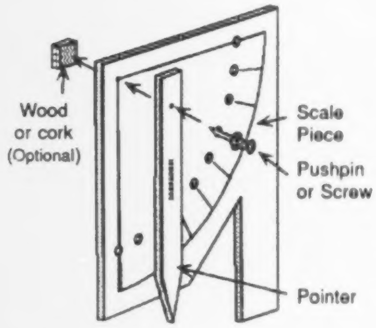
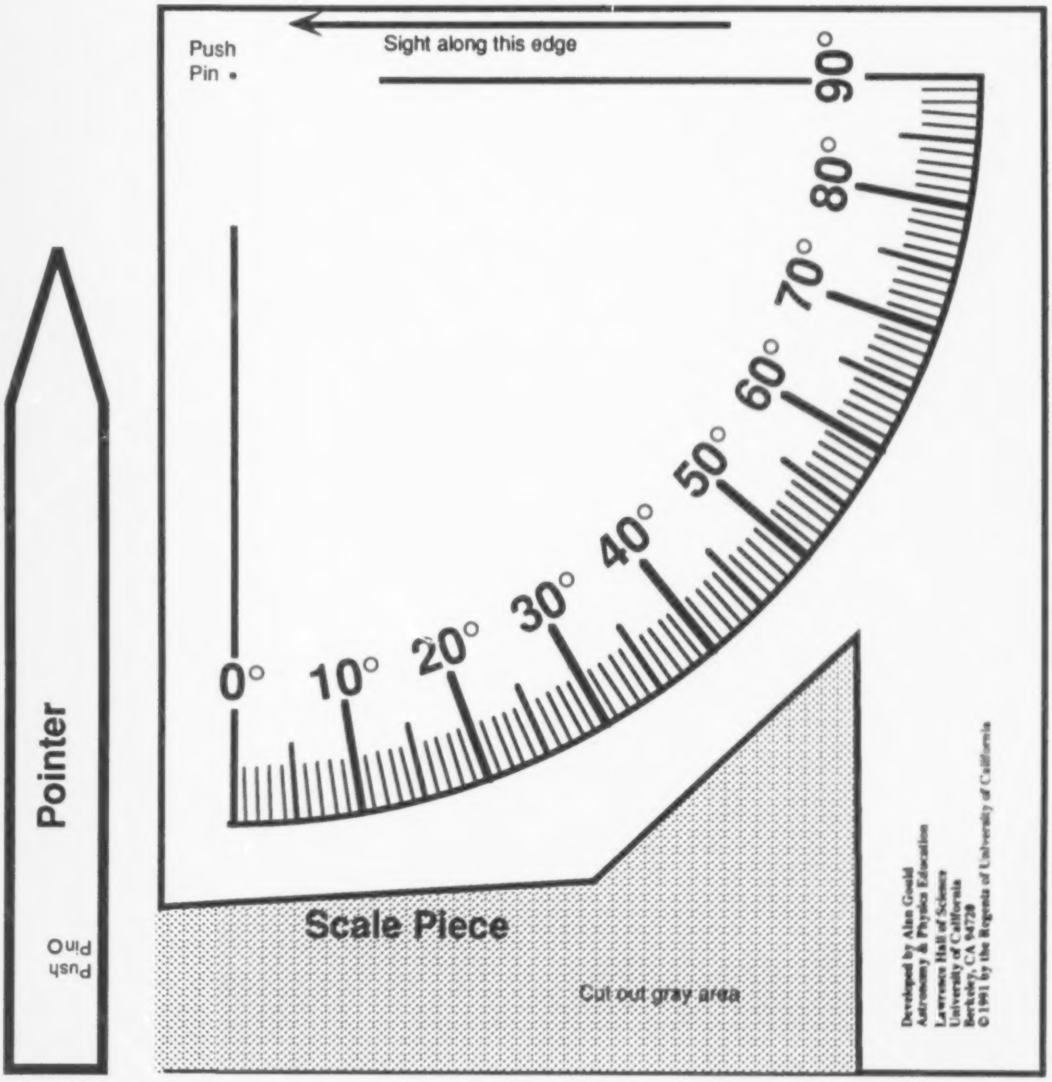

Wood
or cork
(Optional)
Scale
Piece
Pushpin
or Screw
Pointer

Instructions:

- Glue this sheet onto cardboard. Cut out the scale piece, the pointer and the gray area.
- Make a pushpin hole in the pointer at the indicated spot. Enlarge the hole with a pencil tip so that the point will hang loosely on the pushpin.
- Insert a pushpin through the pointer piece, then through the scale piece, and into a small piece of cork, soft wood, or pencil eraser tip. Make sure that the pointer hangs loosely.
- To use, sight on Polaris along the top edge of the scale piece, then press the pointer against the scale piece. Hold the pointer in place and read the altititude angle.

Who "Discovered " America — "Do-It-Yourself" Quadrant

for measuring the altitude of Polaris


Pointer
Push
Pin O
Push
Pin •
Sight along this edge
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°
Scale Piece
Cut out gray area

Developed by Alan Gould
Astronomy & Physics Education
Lawrence Hall of Science
University of California
Berkeley, CA 94720
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STAR FINDING WITH A STAR FINDER

ACTIVITY F-5

GRADE LEVEL: 4-6+

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What's This Activity About?

This activity allows students to create an inexpensive, useful, star chart appropriate for latitudes between 35 and 45 degrees north, which includes most of the continental U.S. These star finders, also known as *planispheres* because they represent a spherical sky on a paper plane, help students locate constellations visible at any time for any date. They can also be used to reinforce the concept that the sky seems to "change" in a predictable pattern.

What Will Students Do?

Students create a simple star finder, using only scissors, staples, glue, copy masters and a stiff paper manila folder. Students answer questions at the end of the activity to help them understand how the star finder is used.

Tips and Suggestions

- Consider assigning additional questions based on the constellations that are visible at the particular time of year when you do this activity.
- The star wheel will not indicate the positions of dim stars between the more prominent constellations, nor will it show the locations of the planets, which vary continuously. As a follow-up activity, once students have gained proficiency with the star finder, use monthly sky charts from astronomy magazines like *Sky & Telescope* or *Astronomy*, which will include more stars, star names, and visible planets.
- Note that many constellations, especially near the southern horizon, will not look as they appear on the flat star finder. The hemispherical sky becomes distorted when compressed to the plane. A constellation like Scorpius, which really does look like a giant scorpion in the southern sky during summer, does not appear in the sky as it is shown on the star finder.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Rotation of the sky during the year	Observing Using Instruments	Patterns of Change Models and Simulations

STAR FINDING WITH A STAR FINDER

A star map of the night sky helps locate different constellations in the same way a road map helps locate different cities on the earth. In this activity students construct a rotating star finder to find the constellations visible in the night sky throughout the year.

CONCEPTS

Constellations remain fixed in their relative position to each other.
Constellations appear in the sky at different times, due to the earth's daily rotation and seasonal orbit around the sun.

OBJECTIVES

Students will:

- construct a star finder.
- identify constellations using a star finder.
- observe the effect of seasonal changes when viewing constellations.

MATERIALS

Star Finder patterns: holder, and two constellation wheels
scissors
file folders (one and one-half per star finder)
glue
stapler

PROCEDURE

Advanced Preparation:
Make enough copies of the Star Finder patterns so each student can make their own. Creating a sample ahead of time will help them understand what the final product should look like.

CONSTRUCTING THE STAR FINDER

1. Distribute one manila folder and the Star Finder Holder pattern to each student.

2. Have students glue the holder pattern to the front of a manila file folder, with the east-south edge of the holder along the fold of the file folder.

3. Have them cut out the star finder as indicated on the pattern, including the central oval. They should staple the front and back together by placing staples exactly on the staple lines shown on the front of the Star Finder Holder.

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4. Distribute copies of the constellation wheels and one-half of a manila folder to each student. Glue one of the constellation wheels to one side of the manila folder. Have them cut it out, then glue the other constellation wheel to the back. This technique makes it easier to line up the circle of the two wheels. It is not possible to align the dates on the two wheels, nor is it important for them to be aligned.

5. Have them insert the star wheel between the pages of the holder so the simple star field appears through the oval opening. Once the star wheel is completely inserted, test turn the star wheel to be sure it moves freely. Check to see that the black line under the dates on the star wheel approximately lines up with the edge of the star finder cover showing the time of day.

USING THE STAR FINDER

1. Before going outside to use the Star Finder, practice using it in the classroom. Have the students align the current date on the wheel with the time indicator on the holder. The following set of questions and directions will help them become familiar with the star finder.
   a. Assume you are going to observe at 9:00 p.m. tonight. What constellations are visible?
   b. Turn the dial until it is set for 11:00 p.m. tonight.
      1. Which constellations are visible?
      2. Which constellations were visible at 9:00 p.m., but are no longer visible at 11:00 p.m.?
      3. Which horizon are disappearing constellations closest to?
      4. Which constellations are visible at 11:00 p.m., but were not visible at 9:00 p.m.?
   c. Turn the dial until it is set for 5:00 a.m., just around sunrise.
      1. Which constellations are still visible that were up at 9:00 p.m.?
      2. Describe the motion the constellations follow from 9:00 p.m. to 6:00 a.m.
      3. Rotate the dial one complete turn, which represents a 24-hour day. Which constellations never go below the horizon?
   d. Hold the star finder over your head so that the "North" designation on the star finder is pointing north. The stars showing in the oval opening are those that can be seen overhead at the time and date set on the star finder. The edge of the oval represents the horizon. Stars near the edge of the oval are low on the horizon. The center of the oval is the point directly overhead when you look up in the night sky. This point is called the zenith. Stars near the center of the oval will be high overhead when you are observing.

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e. Now you are ready to go star finding in the night sky. A small flashlight or penlight will help you read the star finder at night. Red plastic, red construction paper, or a red balloon, over the front of the flashlight will allow you to read your star chart by the red light, but will not reduce your ability to see faint stars in the sky.

Teachers Note: Have students practice using their star finders, pointing to where they would expect to find specific constellations.

2. The simple star field shows the bright stars visible in the major constellations. These stars are easily found, especially when viewing from a city where the many lights make it difficult to see faint stars. Once students are experienced at finding the bright stars on this side of the star wheel, they can flip the star wheel over and attempt to find the fainter stars and constellations. Some of these will not be visible until observed from a location away from city lights.

3. Once students become familiar with some of the brighter constellations, they can use them as guides to find your way around the sky. For example, they can use the two outer stars of the Big Dipper's cup to help find the North Star. Have them devise their own technique to use the stars to find other constellations.

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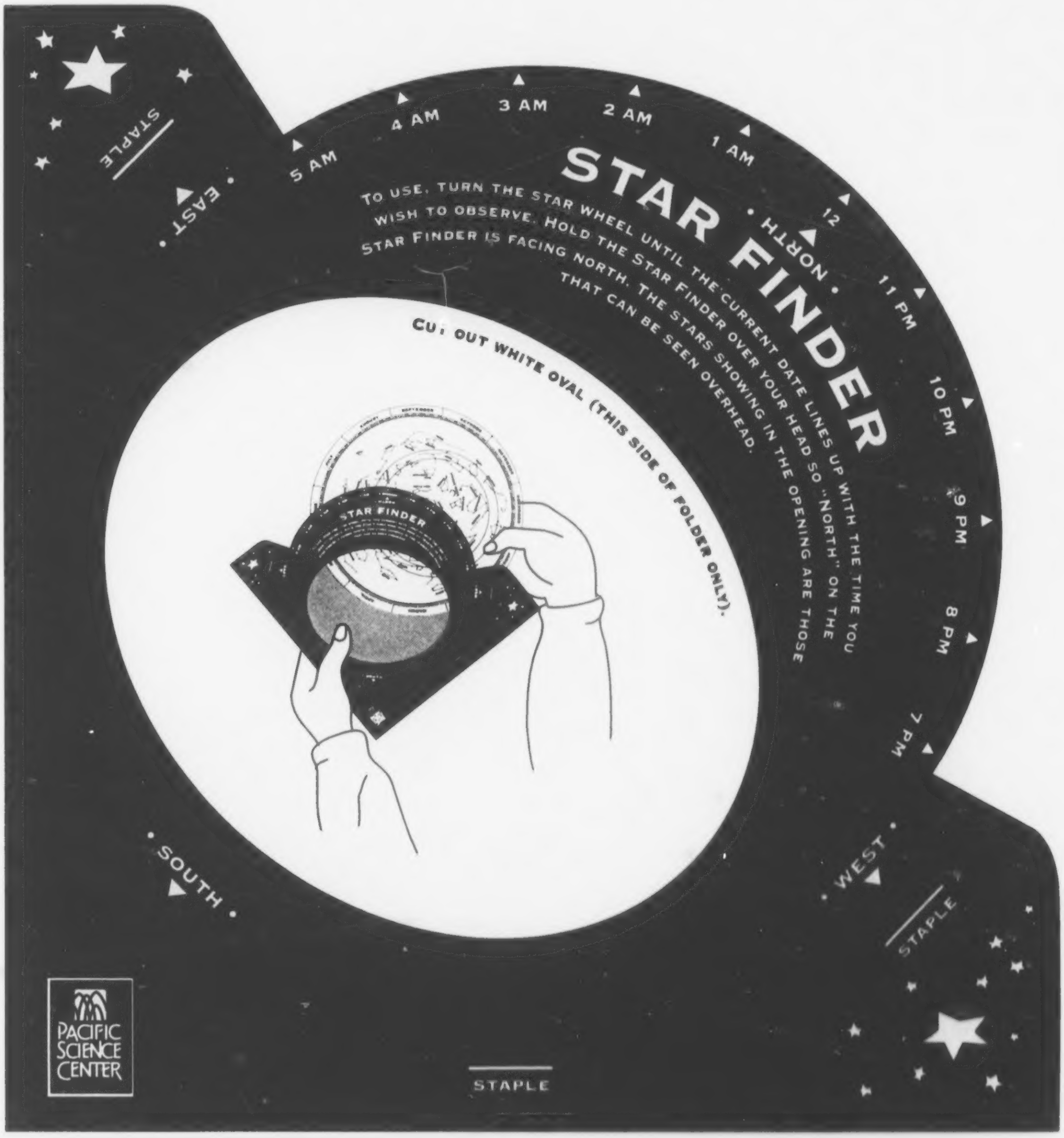
STAR FINDER HOLDER

PASTE ONTO FOLDER, ALIGNING THIS EDGE WITH FOLDED SPINE OF FOLDER. THEN CUT ALONG EDGE OF STAR FINDER, BUT DO NOT CUT FOLDED EDGE!


STAPLE
EAST
5 AM
4 AM
3 AM
2 AM
1 AM
12
NORTH
11 PM
10 PM
9 PM
8 PM
7 PM
WEST
STAPLE
SOUTH
STAPLE
STAR FINDER
PACIFIC SCIENCE CENTER

PLACE THIS SIDE ALONG FOLDING EDGE OF FOLDER.

TO USE, TURN THE STAR WHEEL UNTIL THE CURRENT DATE LINES UP WITH THE TIME YOU WISH TO OBSERVE. HOLD THE STAR FINDER OVER YOUR HEAD SO "NORTH" ON THE STAR FINDER IS FACING NORTH. THE STARS SHOWING IN THE OPENING ARE THOSE THAT CAN BE SEEN OVERHEAD.

CUT OUT WHITE OVAL (THIS SIDE OF FOLDER ONLY).

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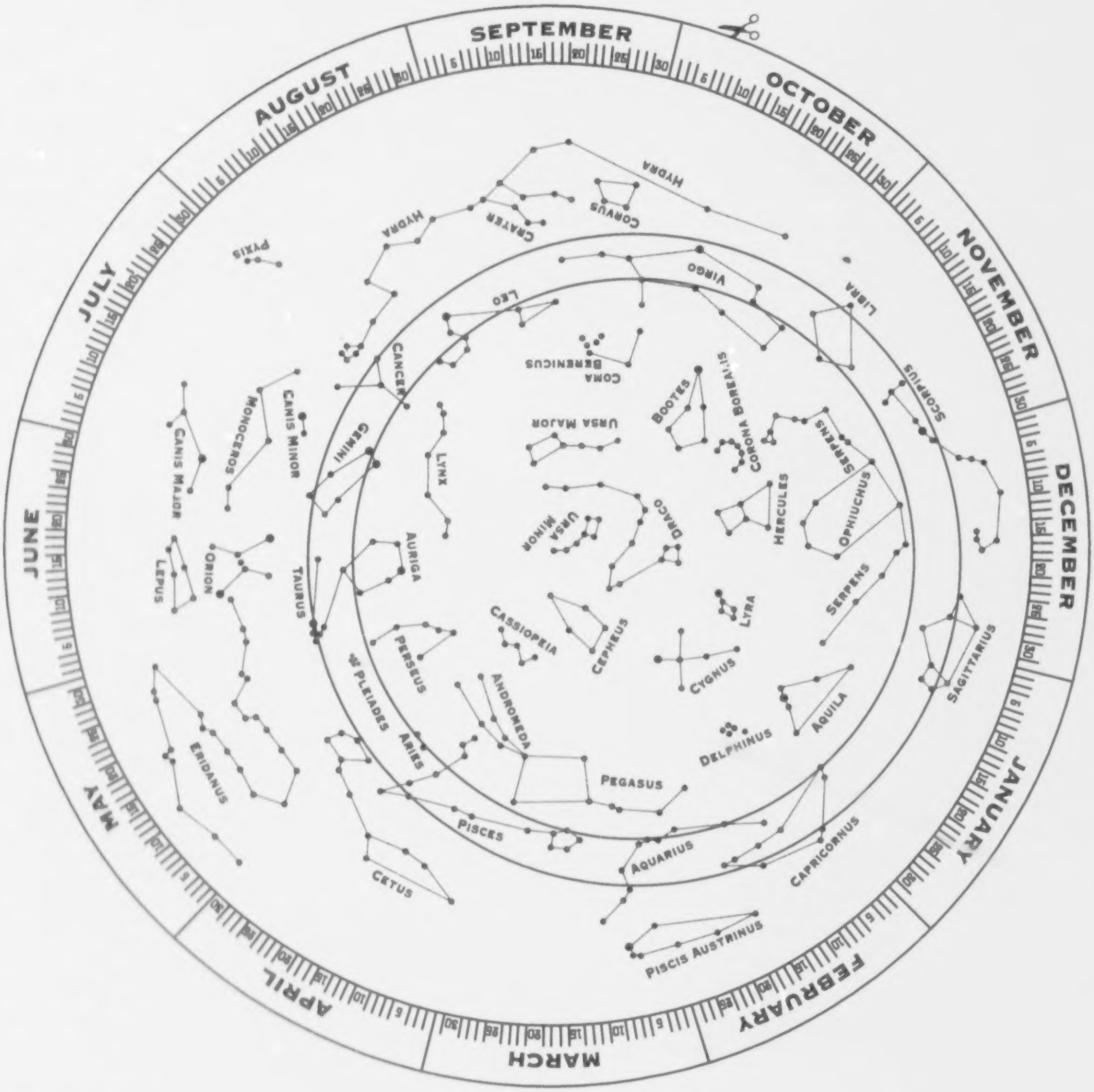
STAR WHEEL
COMPLEX STAR FIELD


SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
HYDRA
CORVUS
CRATER
HYDRA
PYXIS
VIRGO
LIBRA
LEO
COMA BERENICUS
CANCER
SCORPIUS
URSA MAJOR
BOOTES
CORONA BOREALIS
SERPENS
CANIS MINOR
MONOCEROS
CANIS MAJOR
GEMINI
LYNX
HERCULES
OPHIUCHUS
DRACO
URSA MINOR
AURIGA
ORION
LEPUS
TAURUS
LYRA
SERPENS
CASSIOPEIA
CEPHEUS
PERSEUS
CYGNUS
SAGITTARIUS
PLEIADES
ANDROMEDA
ARIES
DELPHINUS
AQUILA
ERIDANUS
PEGASUS
PISCES
AQUARIUS
CAPRICORNUS
CETUS
PISCIS AUSTRINUS

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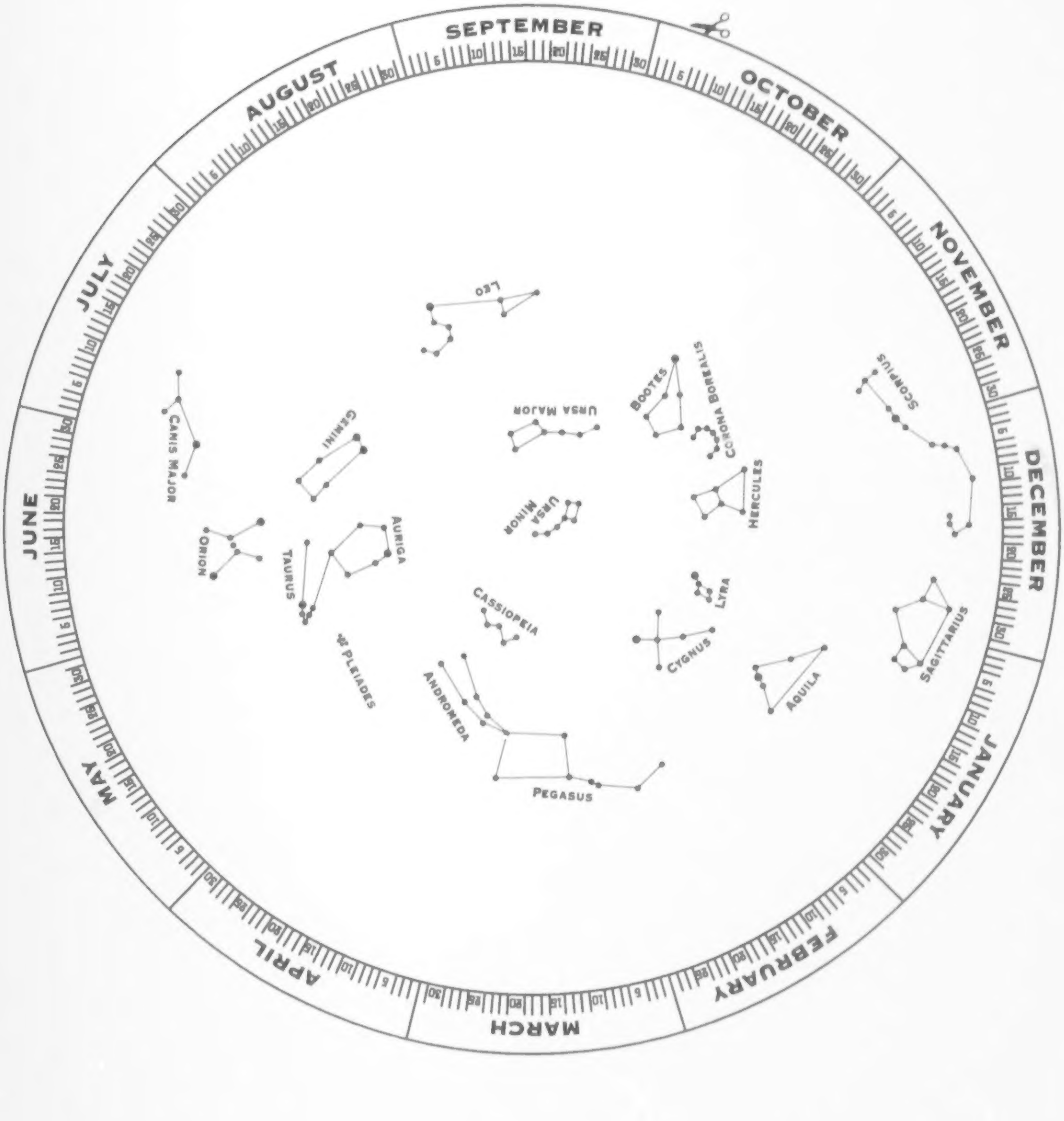
STAR WHEEL
SIMPLE STAR FIELD


SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
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LEO
URSA MAJOR
BOOTES
CORONA BOREALIS
SCORPIUS
CANIS MAJOR
GEMINI
HERCULES
URSA MINOR
AURIGA
ORION
TAURUS
LYRA
CASSIOPEIA
SAGITTARIUS
CYGNUS
PLEIADES
ANDROMEDA
AQUILA
PEGASUS

350

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STAR FRAMES

ACTIVITY F-6

GRADE LEVEL: 3-6

Source: Reprinted with permission from *Starwatch*, by Ben Mayer. Copyright ©1984 by Ben Mayer, The Putnam Publishing Group, New York. (ISBN 0-399-51009-5) (pbck.)

What's This Activity About?

Students often are frustrated with their difficulty identifying constellations. In the classroom, constellation outlines on a star wheel or picture can be easy to spot; usually only one constellation is displayed, or the lights are on! But in the dark of night, finding one constellation among many can be much more difficult.

This activity presents a unique way to help students locate constellations. The transparent pattern allows students to easily find a particular constellation at night.

What Will Students Do?

Students create a transparent constellation pattern map using a coat hanger, plastic wrap, and luminous paint.

Tips and Suggestions

- Create patterns for as many key constellations as you desire. The relative size of the constellations on the frames should be consistent, but does not have to be exactly the same. Students can simply hold the frame closer or farther so that the star pattern matches the stars on the sky.
- We have included a few sample patterns for some easy constellations. Ben Mayer's book can give you other patterns if you and your students enjoy making these frames.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Constellations	Using Instruments Observing	Models

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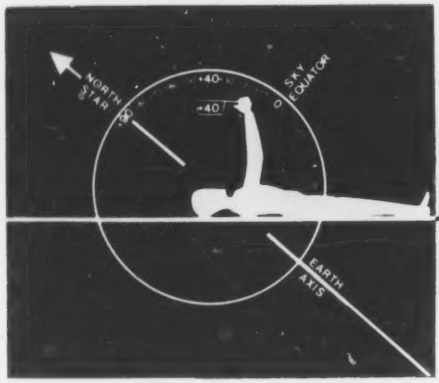
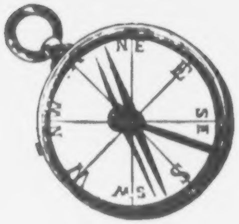


STARFRAMES



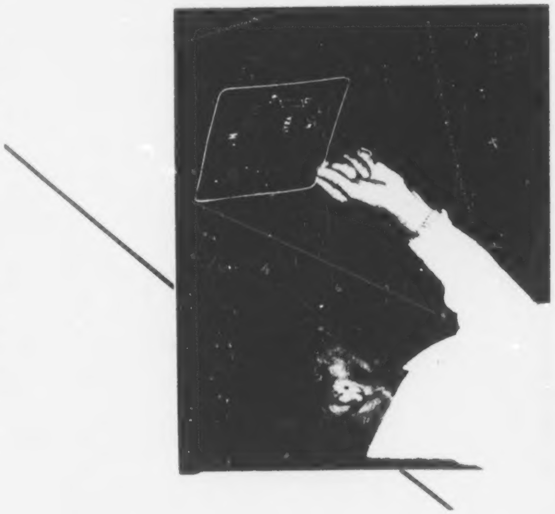
Homemade starframes traced from the pages of this book present a simple new way for everyone to find celestial objects. When you know a constellation's time of culmination (times are given for twenty-four constellations in this book) all that remains for the observer to establish is the north-south direction angle of declination. When the starframe is pointed correctly and two or more of the brightest objects on the tracing are aligned with their counterparts in the sky, everything else falls into place. Once found, constellations can be memorized — even photographed — over a period of several weeks. The diagrams on the left show how to make a standard starframe. Plastic kitchen wrap or any cellophane film will serve as your transparent window to the sky when combined with the lowly wire coathanger. Make a collection, a starframe for each starfield.

With white ink, poster paint or typewriter correcting fluid, trace the principal stars and special objects of interest from the star photo that is given for each constellation in this book. Tiny dots of white can be seen in near darkness by the light of a red-covered flashlight (page 135). If you wish, you can also copy the lines connecting the stars in the constellations. You decide.

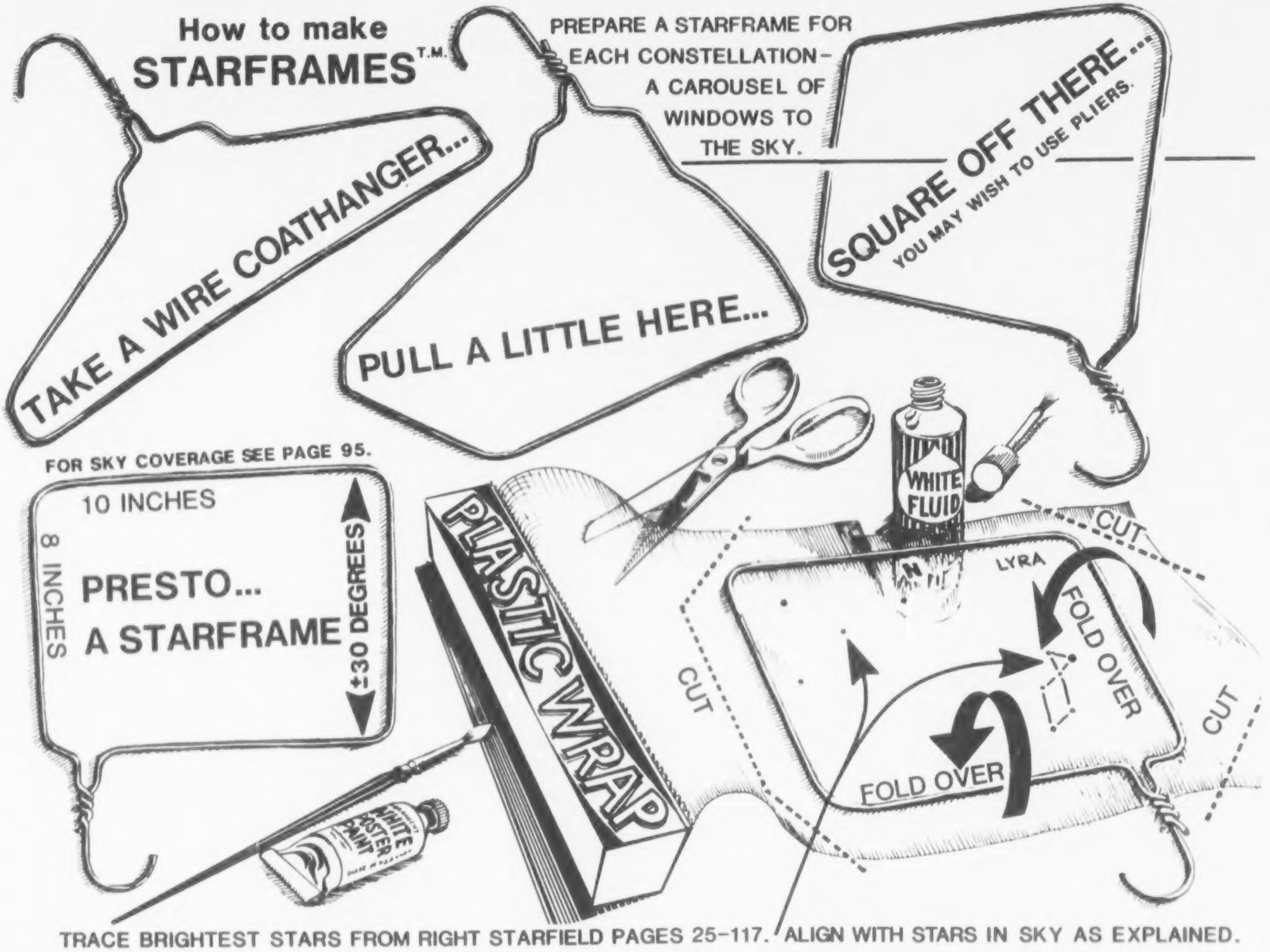
Find a comfortable place in which to lie down, always with your head to the north, feet pointing south. When in doubt about your orientation, use an inexpensive compass to help you find north. At the time of culmination hold the starframe at the angle illustrated in this book for the starfield you want to observe. The distance between the starframe and your eye will need to be established by trial and error, but for most of the starcharts in this book it will be about as shown on this page.

When you view constellations on or near the Band of the Zodiac, be on the lookout for very bright objects that are not shown in our starcharts. Predictably these will be planets wandering through your part of the sky. Try to remember their positions. Over a period of a few days you will be able to notice their motion in relation to the stars. While planets change from direct to retrograde motion or back again, they will appear to be almost stationary for weeks at a time (page 14).

Dress warmly, even summer nights can get chilly. Do not wait until you feel uncomfortable before putting on additional clothing. Anticipate dropping temperatures by adding layers of apparel before you feel the need for them. Avoid perspiration at all costs. Only dry fabrics can efficiently protect you from the cold. Put on extra socks. When your feet are warm, the rest of you will be comfortable, too.



STARFRAMES ™


How to make
STARFRAMES T.M.
PREPARE A STARFRAME FOR EACH CONSTELLATION– A CAROUSEL OF WINDOWS TO THE SKY.
TAKE A WIRE COATHANGER...
PULL A LITTLE HERE...
SQUARE OFF THERE...
YOU MAY WISH TO USE PLIERS.
FOR SKY COVERAGE SEE PAGE 95.
10 INCHES
8 INCHES
±30 DEGREES
PRESTO...
A STARFRAME
PLASTIC WRAP
WHITE POSTER PAINT
WHITE FLUID
LYRA
N
CUT
CUT
CUT
FOLD OVER
FOLD OVER
TRACE BRIGHTEST STARS FROM RIGHT STARFIELD PAGES 25–117. ALIGN WITH STARS IN SKY AS EXPLAINED.

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364

365

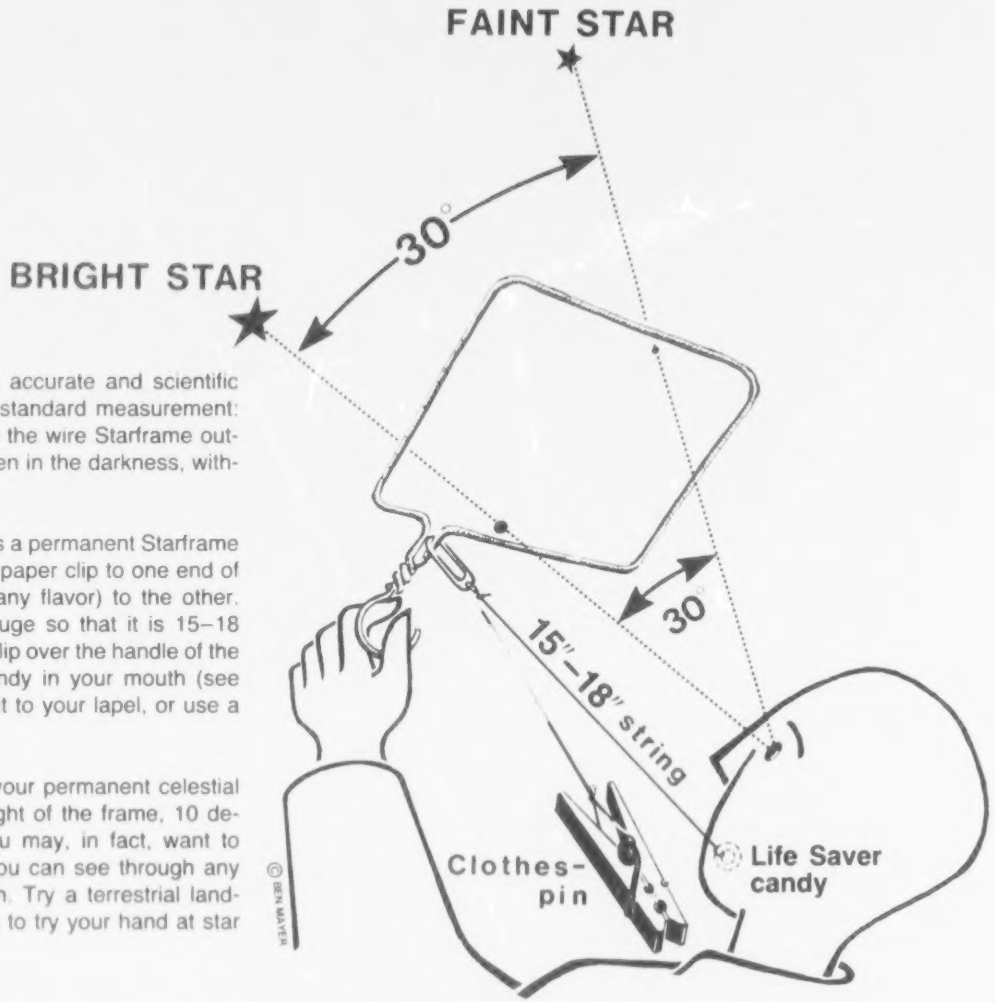

ILLUSTRATION 03

In order to make our Starframe into an accurate and scientific instrument, we need maintain only one standard measurement: the 15–18-inch distance from the eye to the wire Starframe outline. This can be easily standardized, even in the darkness, without any measuring at all.

Prepare a short piece of string to serve as a permanent Starframe distance gauge. You only need attach a paper clip to one end of the string and tie a Life Saver candy (any flavor) to the other. Measure the overall distance of the gauge so that it is 15–18 inches *from end to end*. Snap the paper clip over the handle of the Starframe, then hold the Life Saver candy in your mouth (see illustration 03). You can also safety-pin it to your lapel, or use a clothespin.

The basic wire Starframe will serve as your permanent celestial viewfinder. Since 30 degrees is the height of the frame, 10 degrees would be one-third of it, etc. You may, in fact, want to compare the area to the field of view you can see through any camera viewfinder of a subject on earth. Try a terrestrial landscape. This will logically make you want to try your hand at star photography.

When you stretch some transparent acetate kitchen wrap over your basic wire Starframe, you can convert it into a veritable window to the sky.

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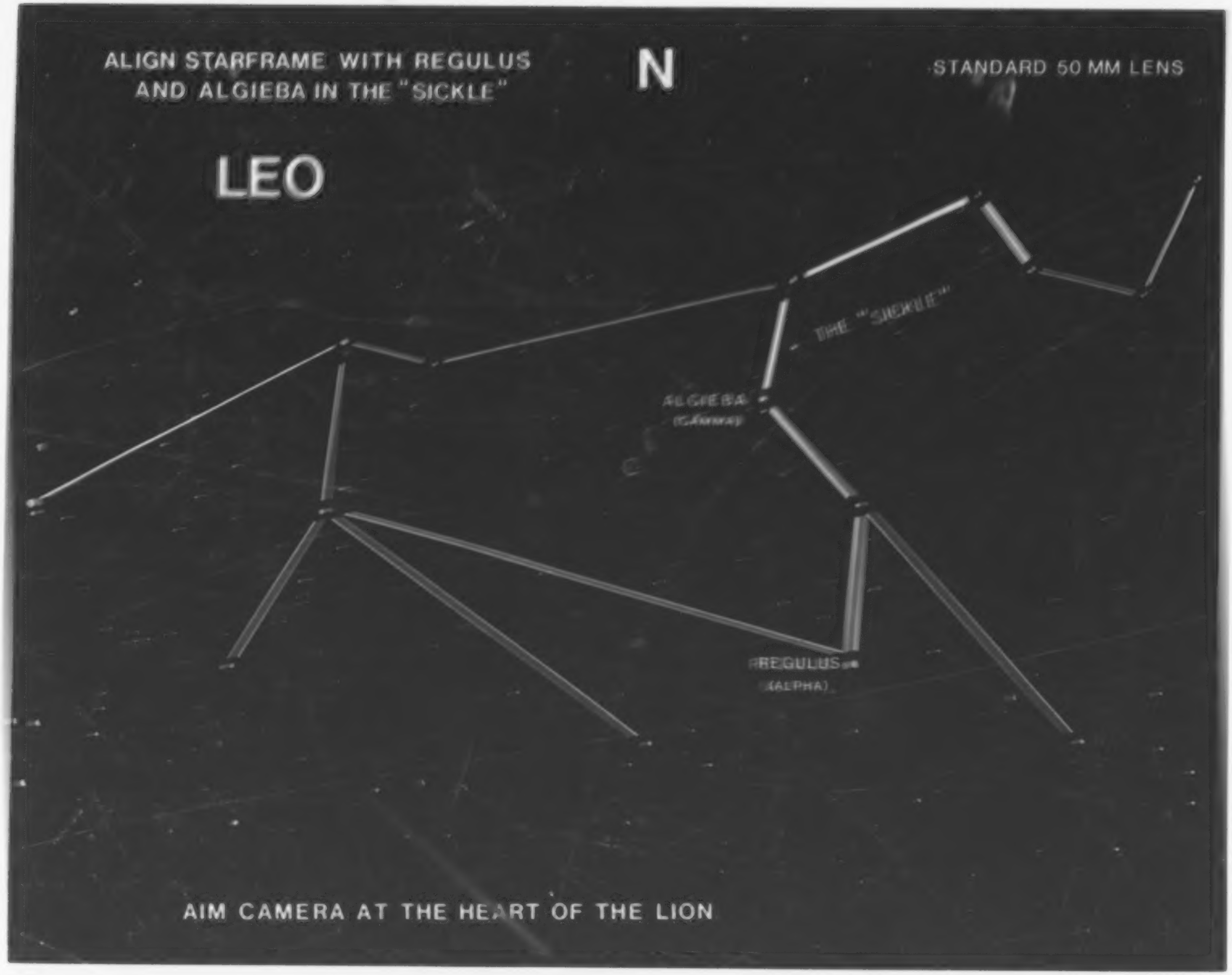
ALIGN STARFRAME WITH REGULUS
AND ALGIEBA IN THE "SICKLE"
N
STANDARD 50 MM LENS
LEO
THE "SICKLE"
ALGIEBA
(GAMMA)
REGULUS
(ALPHA)
AIM CAMERA AT THE HEART OF THE LION

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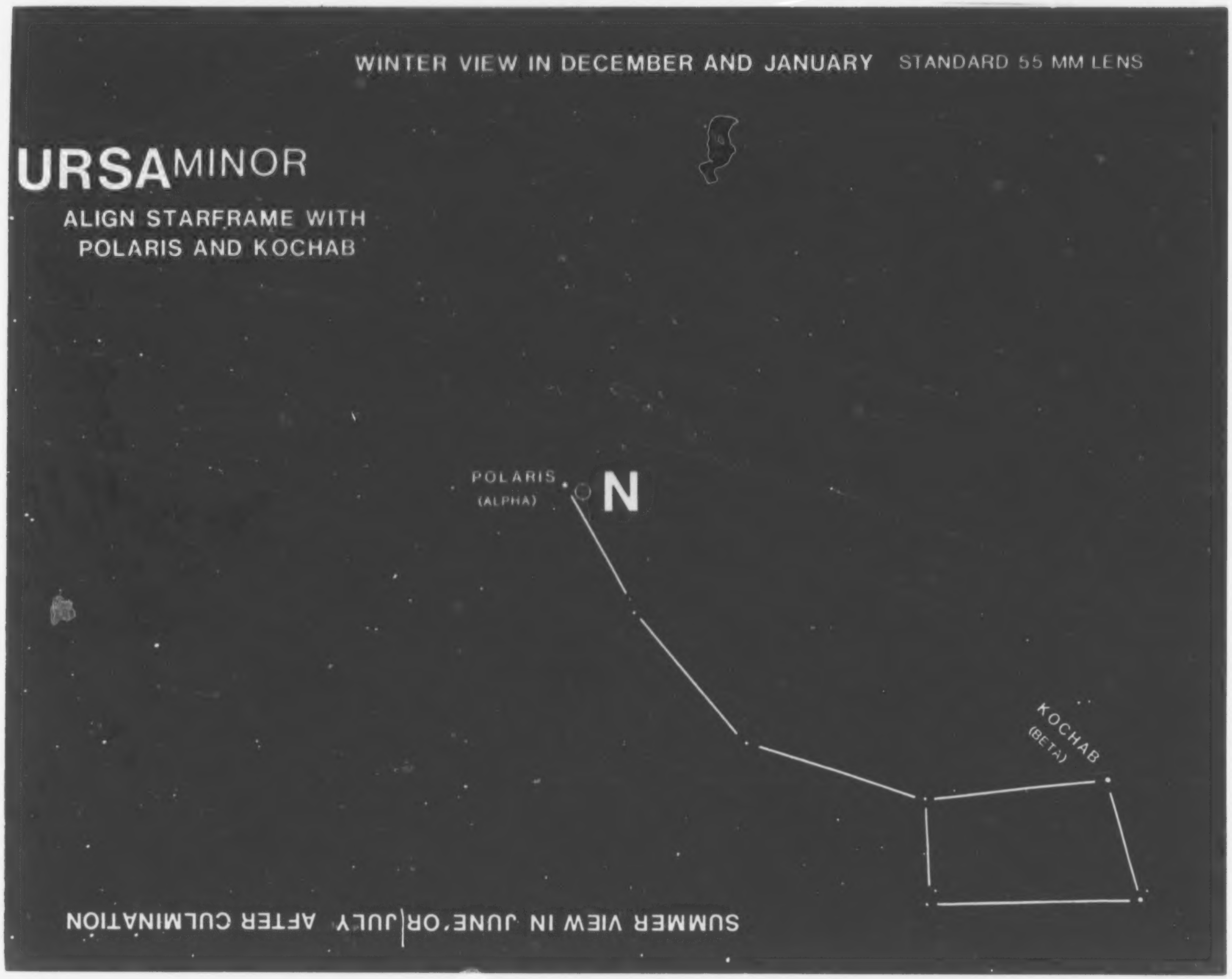
WINTER VIEW IN DECEMBER AND JANUARY
STANDARD 55 MM LENS
URSA MINOR
ALIGN STARFRAME WITH
POLARIS AND KOCHAB
POLARIS
(ALPHA)
N
KOCHAB
(BETA)
SUMMER VIEW IN JUNE OR JULY AFTER CULMINATION

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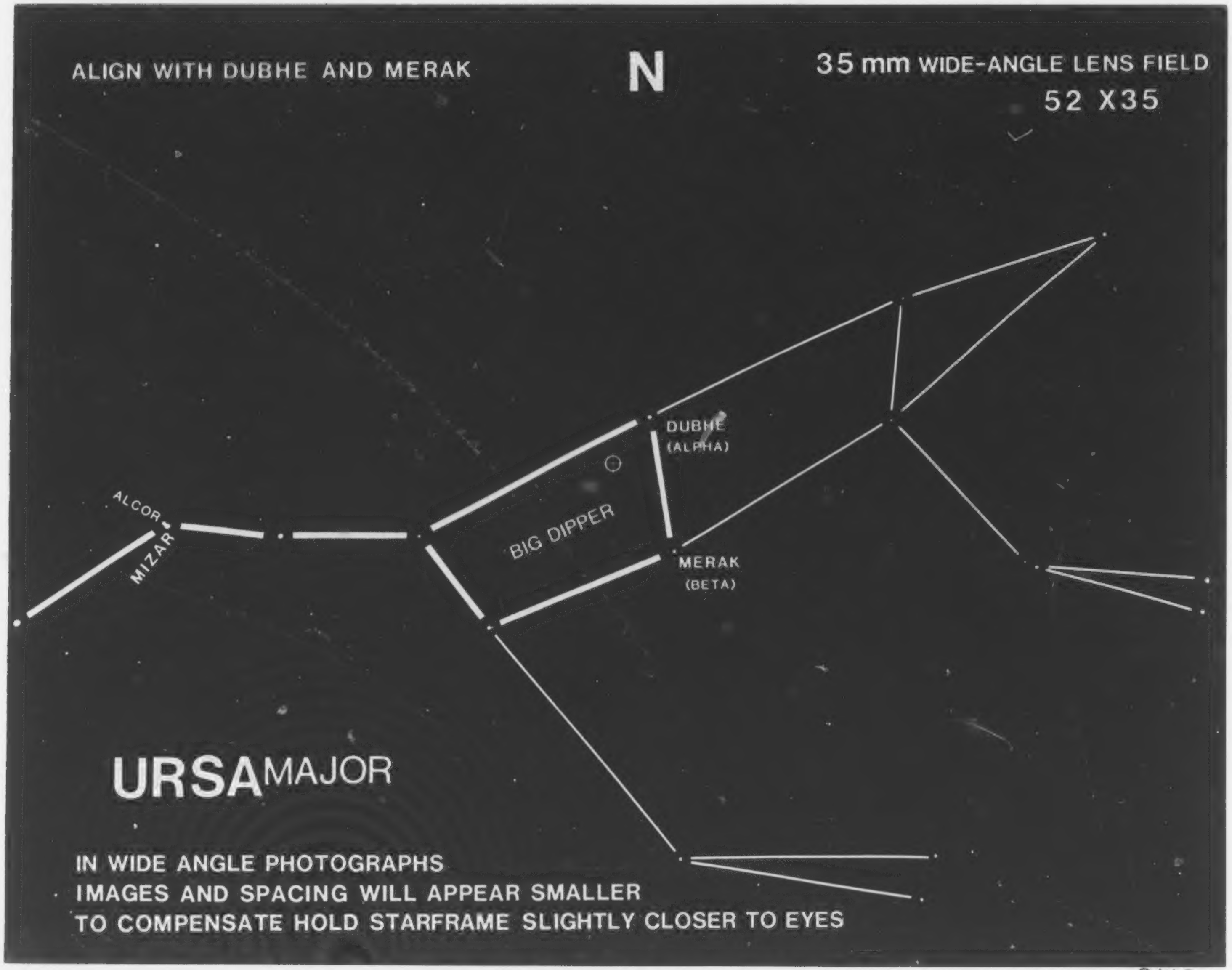
ALIGN WITH DUBHE AND MERAK
N
35 mm WIDE-ANGLE LENS FIELD
52 X35
DUBHE
(ALPHA)
MERAK
(BETA)
ALCOR
MIZAR
BIG DIPPER
URSA MAJOR

IN WIDE ANGLE PHOTOGRAPHS
IMAGES AND SPACING WILL APPEAR SMALLER
TO COMPENSATE HOLD STARFRAME SLIGHTLY CLOSER TO EYES

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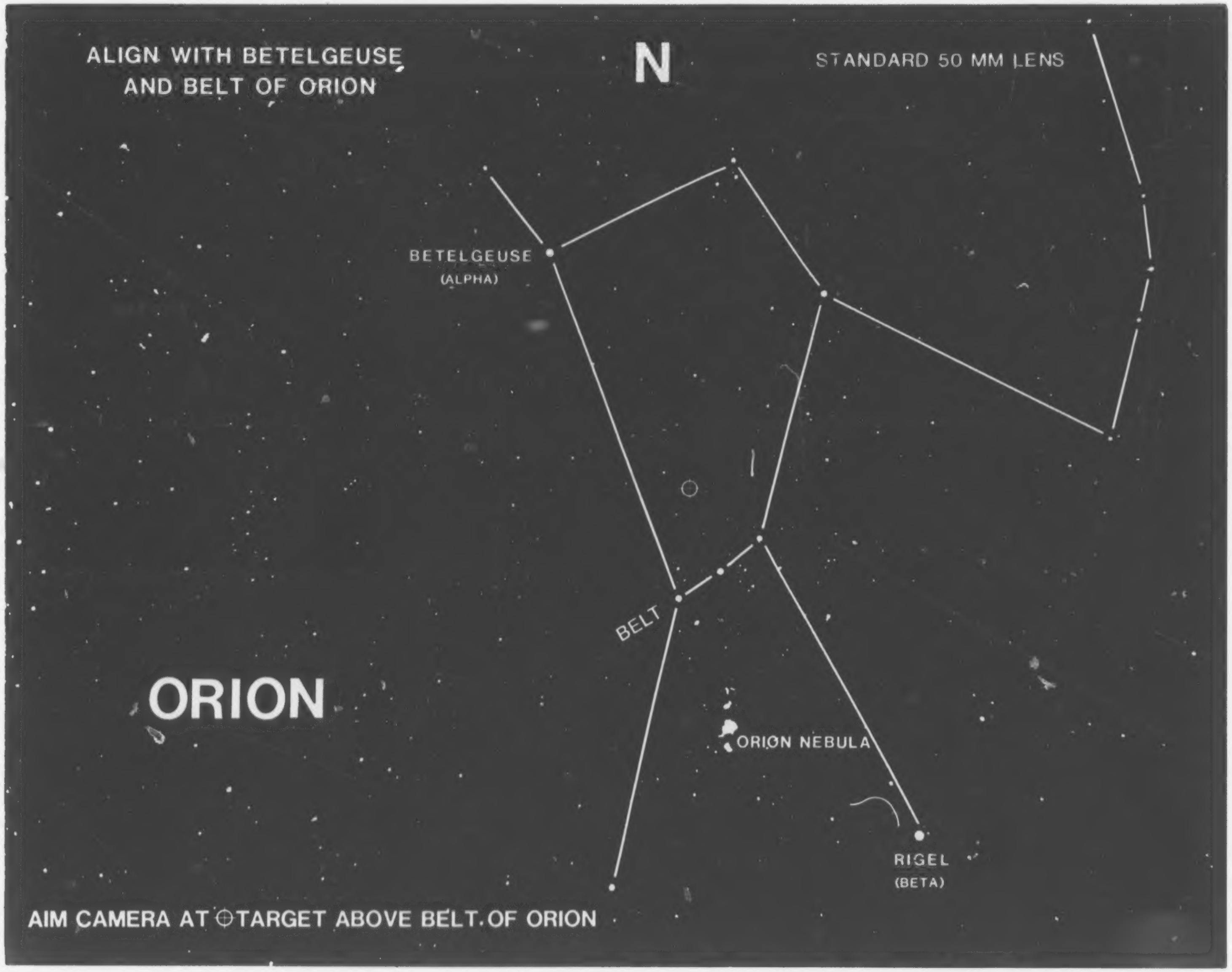

ALIGN WITH BETELGEUSE AND BELT OF ORION

STANDARD 50 MM LENS

N
BETELGEUSE
(ALPHA)
BELT
ORION
ORION NEBULA
RIGEL
(BETA)

AIM CAMERA AT ⊕TARGET ABOVE BELT OF ORION

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CREATING CONSTELLATIONS

ACTIVITY F-7

GRADE LEVEL: 4-7

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What's This Activity About?

This activity provides a nice way to introduce the idea of a constellation to earlier grades. Pattern recognition is developed first, and then applied to the stars in our sky. Students start with a circle puzzle, which may at first seem totally unconnected to the theme of constellations. But looking for patterns, whether in a familiar circular shape or in the skies, is a critical element for the recognition of constellations. Students advance to a connect-the-dots puzzle, which also can be used as a model for the constellation of Cassiopeia.

What Will Students Do?

Students draw familiar pictures and shapes within blank circles, and then create their own patterns from an arrangement of dots similar to the stars of Cassiopeia.

Tips and Suggestions

- Create additional blank constellation dot patterns for homework.
- One novel source for constellation patterns is *The Box of Stars* by Catherine Tennant, a package of 32 beautiful constellation cards with appropriately-sized pin holes. (ISBN 0-8212-2038-1; published by Bullfinch Press of Little, Brown, and Company; retail $24.95, and available from the Astronomical Society of the Pacific.)

What Will Students Learn?

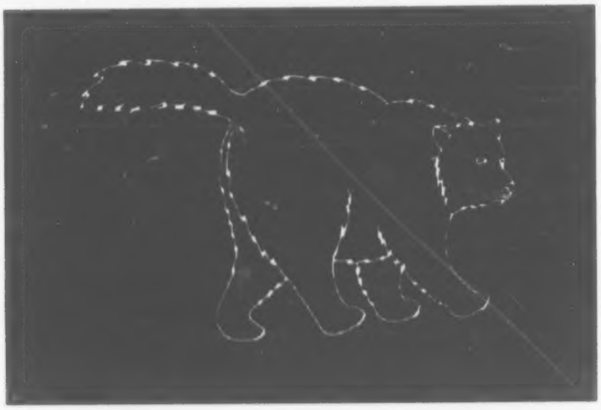
Concepts	Inquiry Skills	Big Ideas
Pattern recognition	Imagining Visualizing Communicating	Patterns of Change Models and Simulations

Creating Constellations

This science activity is designed for students in grades three through eight. It can be presented by teachers with no special preparation in science. Creating Constellations is keyed to concepts in the planetarium program, *Constellations Tonight*, so it will probably be most effective if presented just before or just after visiting the planetarium. Each teacher may wish to adapt the language and pace of the activity to his or her particular class.

Objectives

This activity involves the stage of scientific thinking in which many different ideas, or hypotheses, are generated. It focuses on the type of problems that have many equally good solutions (like naming a new animal) in contrast to problems that have only one right answer (like finding the North Star). After the lesson, the students will be able to:



1. Recognize that several different ideas may be equally good solutions to the same problem.

2. Recognize when they need to "break set"—that is, to find a new approach to the problem. (Set breaking can be thought of as "getting out of a mental rut.")

3. Recognize that the constellations which they invent can be just as useful as the ancient Greek and Roman constellations.

Before Class

1. Duplicate one copy of the Circle Puzzle, Dots Puzzle, and Create a Constellation for each student (masters on pp. 23, 25, and 27 respectively). Prepare large sheets of paper and crayons.

2. Have board space and tape ready to display the students' work.

3. On a different section of the blackboard draw three or four circles, about 18-20 inches in diameter.

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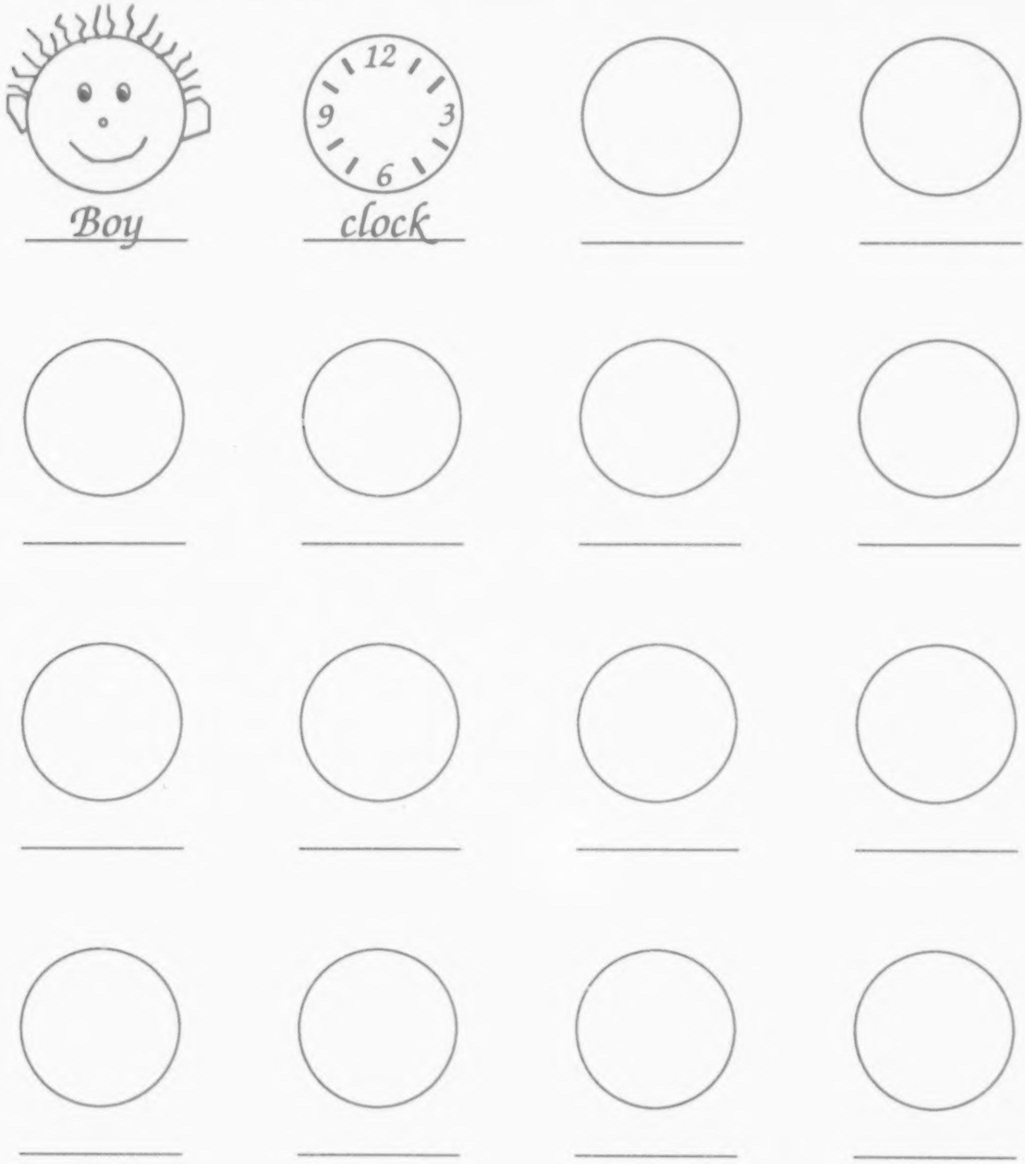
CIRCLE PUZZLE

Make each circle into a picture of something and write a name for what you draw underneath. The first two circles are completed as examples. Notice that each one is DIFFERENT and each one has a name.



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Part A. Circle Puzzle

Here is a puzzle that has many equally good answers. Make each circle into a **different** picture, and **name** what each picture shows.

Hand out the Circle Puzzle. Read the directions with the students if necessary. Then allow about ten minutes for them to work.

Who would like to come to the board to show one of their ideas?

Three or four students draw in the prepared circles on the blackboard.

Share your papers with your neighbors to see how many different ideas you can count. ***How many did you find? How many different possibilities do you think there are?***

How many of you thought of a few different ideas for the circles, and then just couldn't think of any more? What are some different things you could try at that point, to think of a different idea?

Let the students share strategies for generating new ideas that THEY find useful. Examples of strategies are: look around the room for round objects, imagine my room at home, share ideas with someone else, and so on.

Part B. Dots Puzzle*

Directions for this puzzle are very similar to the Circles Puzzle, only you create figures out of dots instead of circles.

Hand out one copy of Dots to each student. Give them about five minutes to work.

Now compare your drawings with your neighbors' drawings. ***Did any of you have the same idea? How many different ideas can you count?***

Let the students discuss their ideas with their neighbors for a minute or two. Then, hand out the last sheet, entitled "Create A Constellation."

On this sheet you will probably recognize the same pattern of dots that you saw in the Dots Puzzle. This is actually a pattern of stars visible in the sky. Ancient Greek astronomers, who lived about 2000 years ago, saw the Queen of Ethiopia, called Cassiopeia (pronounce: Kasio-pee-ah) in this pattern of stars.

Cassiopeia is an especially easy constellation to find just about any time of the year.

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* The activities described in Part B have been adapted from "An Introduction to Constellation Study (or Isn't That Big Bird in the Sky?)" by Gerald Mallon. Published in Science and Children, November/December, 1976, Vol. 14, No. 3, pp. 22-25.

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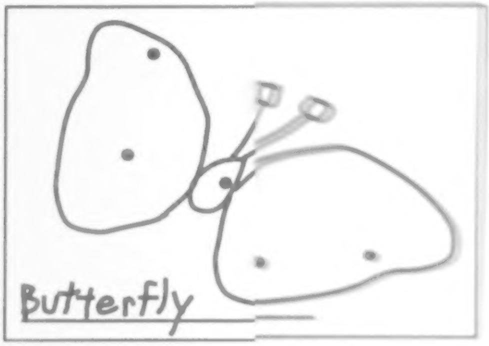
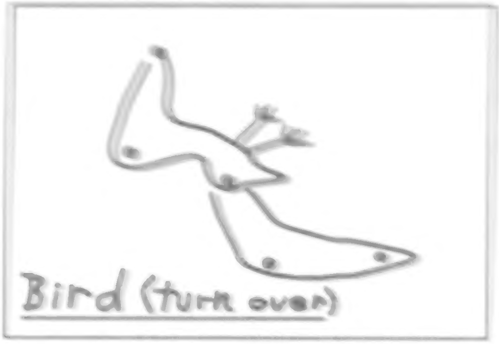
DOTS PUZZLE

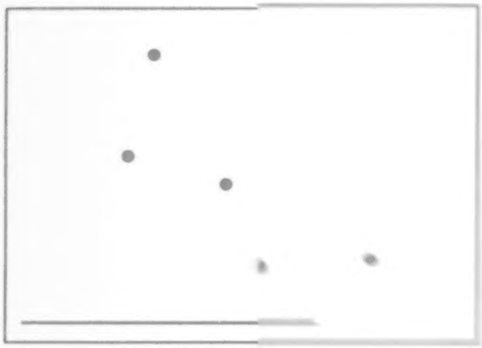
These six pictures all show the same pattern of dots. In the first two pictures, people have drawn something which the dots make them think of. They labeled their pictures with a name that tells what the drawing is supposed to be.

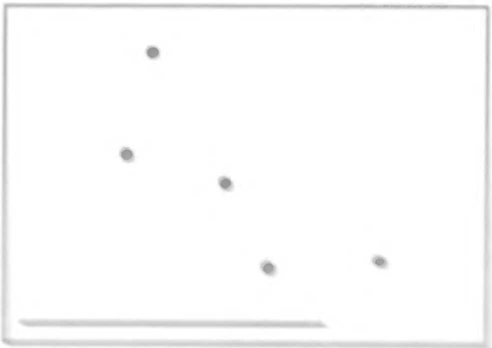
INVENT FOUR COMPLETELY DIFFERENT THINGS BASED ON THE SAME PATTERN OF DOTS.

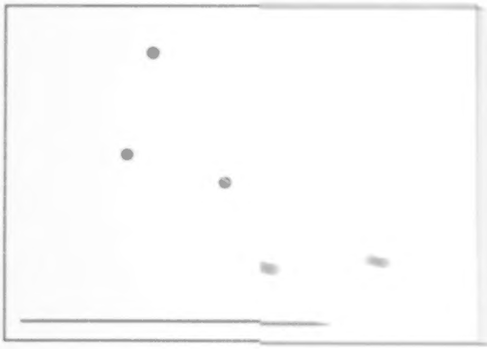
Draw your ideas in the last four boxes and label each one to tell what it is supposed to be a picture of.

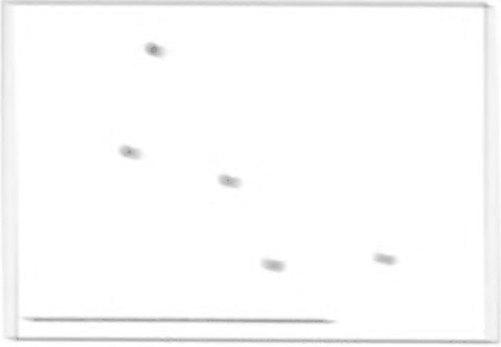












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A picture and name that anyone imagines when he or she looks at a pattern of stars is called a "constellation." In the box at the bottom of the page, draw the idea which YOU like best and name it. This is your own constellation which you can find in the night sky. When you are working by yourself, your own constellation invention is just as useful, perhaps even better, than the "classic" ones.

Would it sometimes be better for us all to agree on a single constellation for everybody to use? How would that be useful?

Possible answers to this question might be: "To tell someone else where to find certain stars, or directions in the sky."

For astronomers, the word "constellation" has a more specific meaning that refers to a particular region of the sky. To make it easy to refer to areas of the sky, the whole celestial sphere is divided into the 88 classic constellations.

Any arbitrary group of stars that form a picture other than those 88 constellations is referred to as an "asterism."

For example, Ursa Major is a constellation, but the Big Dipper is an asterism within the constellation Ursa Major.

In colloquial usage, the word *constellation* is often used to mean the same thing as an asterism. In the following activity, we are not actually making up constellations in the narrow (astronomical) sense of the term. Astronomers all over the world will not recognize "made up" constellations!

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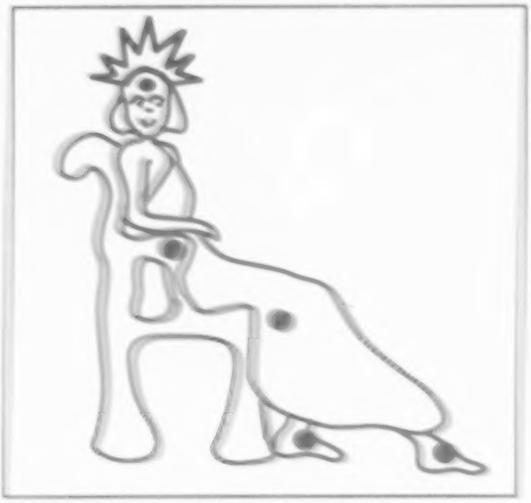
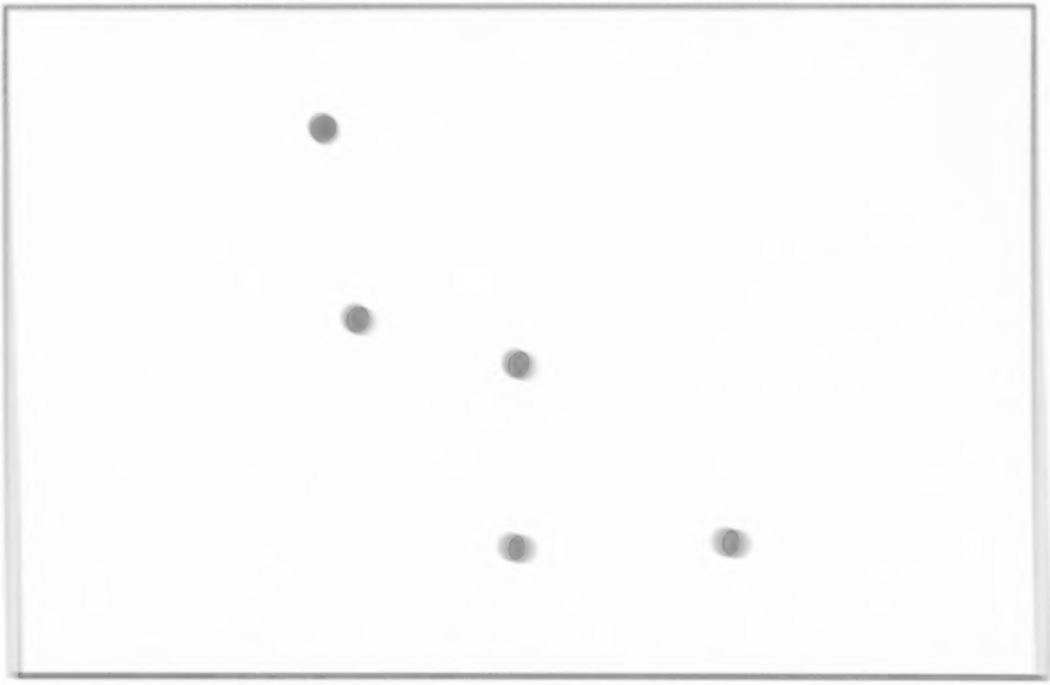
CREATE A CONSTELLATION



The Queen Cassiopeia Sitting On Her Throne

The pattern of dots from the "Dots Puzzle" is really a pattern of stars that you can find in the sky. The Ancient Greeks saw this pattern as a beautiful queen, Cassiopeia, sitting on a throne.

In the box below, create your own constellation for the same pattern of stars.



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Follow-Up Activities

1. Have the students invent myths which tell the story of their constellations. This activity might be preceded by having them read ancient Greek, Roman, or Native American star myths which appear in many anthologies for children.

2. Have the students draw or paint more detailed pictures of the constellation figures they have created to illustrate their stories. Instruct them to show where the stars appear in the pictures.

3. The quiz on page 37 may be used as a pre-test and/or post-test to find out how well your students understand the concepts in this program. Please note that some questions refer to "Creating Constellations," while others refer to "Using a Star Map" or CONSTELLATIONS TONIGHT. You should revise this test as needed to fit your particular classroom situation.

4. Sheldon Schafer of the Lakeview Museum in Peoria, Illinois recommends the following activity, best done just after the circle puzzle, to demonstrate the value of using constellation figures.

a. Draw a random assortment of dots on the board.

b. Ask the students to memorize the arrangement. Allow a minute or two. No notes should be taken.

c. Erase the dots COMPLETELY.

d. Ask for a volunteer to recreate the pattern on the board or have all students do so on a piece of paper.

e. Compare the results with the original.

f. Draw a new pattern of dots on the board, this time connected into some kind of figure.

g. Repeat steps b-f.

h. Compare the results of the first trial with those of the second. Usually there will be an easily noticeable difference between the two.

Make a Constellation

Edna DeVore from Independence Planetarium in San Jose, CA contributes this activity in which individuals or teams of students make constellation projectors:

Materials (for each student or team):

For Projection Constellation
~overhead projector
~square of aluminum foil (25x25cm)
~star map for the season
~paper clip or sharp pencil
~rubber band

For Viewer Constellation
~soup cans without ends or similar-sized tubes
~square of aluminum foil (10x10cm)
~star map for the season
~paper clip or sharp pencil

In Class

1. Students select (or are assigned) a constellation from a star map.
2. Using a pencil or straightened paper clip, students transfer the star pattern to the aluminum foil. For the Viewer type, the pattern must be smaller than the can diameter.
3. To project: place aluminum squares on overhead projector, turn on light and ask students to identify with their star maps.

   To view: place aluminum foil over the end of the can and secure it with a rubber band. View by looking toward a bright light. Identify the pattern by using star maps. Be careful to place the pattern "right-side-up" or "right-side-out" so that the images are seen correctly, not a mirror image.

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THREE-DIMENSIONAL CONSTELLATIONS

ACTIVITY F-8

GRADE LEVEL: 4-9

Source: Reprinted by permission from *Project Pulsar*, St. Louis Science Center, 5050 Oakland Avenue, St. Louis, MO 63110. Publication is no longer in print.

What's This Activity About?

We see the sky as the inside of a great bowl over our heads, with all the stars of a constellation at the same apparent distance, and just different in brightness or color. In reality, stars in constellations usually are not physically near each other, but instead just appear in the same general direction. This activity is fun, and it can serve as a launchpad for discussions into how we actually measure the distances to stars.

What Will Students Do?

Students create a three-dimensional model of a constellation by standing at different distances from a student observer representing the Earth. The model uses distances as well as position in the sky and allows students to visualize space around our Sun from different perspectives.

Tips and Suggestions

- To create models of other constellations, consider the book *Nightwatch* by Terence Dickinson, which contains wonderful star maps with distances to key stars.
- Current astronomy software, like *Dance of the Planets* (DOS), *Redshift*, or *Voyager II* (Mac) also enable students to view nearby space from different perspectives and to visualize constellations in 3-D.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Space as three-dimensional	Ordering	Scale
Constellations as groups of stars	Visualizing	Structure

KEY QUESTION How far away from the Earth are the stars? (They are at different distances from the Earth.)

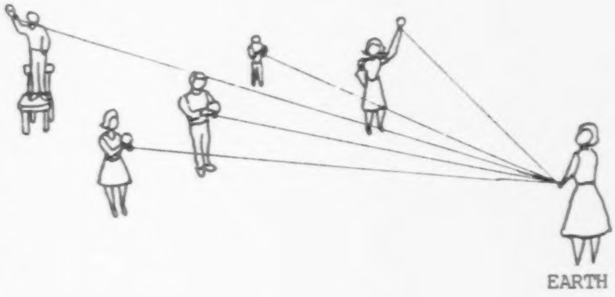
MATERIALS string, scissors, aluminum foil, styrofoam balls (optional)

VOCABULARY constellations, light-year

BACKGROUND Estimating Distances to Stars, Star Brightness I, II, & III, Constellation Search, Looking Back In Time

THE MODEL A styrofoam ball covered with aluminum foil, or just a ball of foil, will represent a star. The string will be used as celestial yardsticks for measuring the distances to individual stars. For example, if a star is 70 light-years from Earth, cut a piece of string 7 ft. long, and let each foot equal a distance of 10 light-years. If a star is 700 light-years away, cut a length of string 7 ft. long, and let each foot equal a distance of 100 light-years. However, be sure to use the same scale factor in the same model.

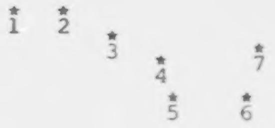
OBSERVATION Pick a place which will represent the position of the Earth. Use the tables and charts to cut lengths of string as described above. Have an observer at the Earth location hold one end of each string. Other students, holding the foil balls, should hold the other ends, and be "eyeball" positioned by the observer at Earth to match the following diagrams. Then have your students observe the constellations from the Earth location.

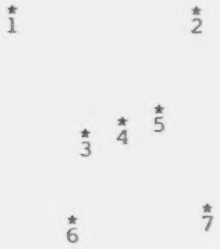


continued

THREE-DIMENSIONAL CONSTELLATIONS

STAR PATTERN	STAR NUMBER	DISTANCE (L.Y.)
Big Dipper (part of Ursa Major)	1	150
	2	88
	3	82
	4	63
	5	90
	6	78
	7	104
Orion (does not include all stars)	1	652
	2	303
	3	1467
	4	1532
	5	1500
	6	1826
	7	815

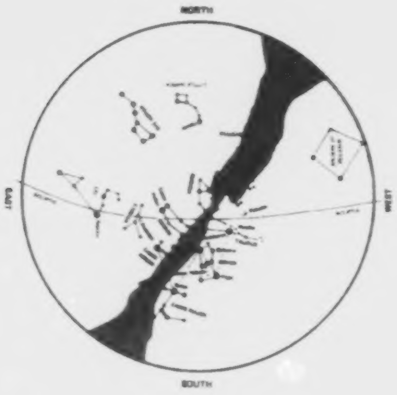




SPECULATION After your students have observed these star patterns from the Earth position, ask them to speculate about how the Big Dipper would look from other places in space. Where would one go to see a star pattern completely reversed?

EXPERIMENT Have your students move around, and through, the star patterns to see how they would look from other places in the galaxy. This activity is basically intended to show students that constellations are not flat, as they appear in the night sky.

RESEARCH Have your students find the distances to other stars in order to construct other 3-D star patterns.



RESOURCES FOR EXPLORING CONSTELLATIONS AND NIGHT SKY OBSERVING

by Andrew Fraknoi
Astronomical Society of the Pacific
390 Ashton Ave.
San Francisco, CA 94112

Here we consider some of the most useful printed or audiovisual resources for becoming familiar with the sky and for using one's own binoculars or telescope to explore the heavens. There are also many computer programs to assist the novice astronomer in finding his or her way around. These are listed and reviewed in articles in the *Resources & Bibliographies* section of this notebook. Note that resources marked with a • are especially useful for those just beginning their exploration of the night sky.

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

Basic Books for Learning the Bright Stars and Constellations

Bakich, M. *The Cambridge Guide to the Constellations.* 1995, Cambridge U. Press. A detailed guide to the history, lore, and stars of the constellations.

• Berry, R. *Discover the Stars.* 1987, Harmony/Crown. A fine introductory book for beginners by the former editor of *Astronomy* magazine, with clear maps and text.

Beyer, S. *The Star Guide.* 1986, Little Brown. An introduction to the 100 brightest stars and how to find them in the sky.

• Chartrand, M. *Skyguide.* 1982, Golden Press. Compact, inexpensive handbook for the novice, full of useful information.

Dickinson, T. *NightWatch: An Equinox Guide to Viewing the Universe.* 1989, Camden House. Nicely illustrated guide by a Canadian amateur astronomer and science writer.

Eicher, D. *The Universe from Your Backyard.* 1988, Cambridge U. Press. For deep-sky observers with a small telescope.

Ellyard, D. & Tirion, W. *The Southern Sky Guide.* 1993, Cambridge U. Press. A short manual to the constellations of the southern hemisphere, with good maps.

Harrington, P. *Touring the Universe Through Binoculars.* 1990, John Wiley.

• Moore, P. *Exploring the Night Sky with Binoculars.* 1986, Cambridge U. Press. A friendly introduction by a prolific British author and astronomy popularizer, with clear instructions.

Motz, L. & Nathanson, C. *The Constellations: An Enthusiast's Guide to the Night Sky.* 1988, Doubleday. An introduction to the mythology and science of the sky, organized by constellation.

Pasachoff, J. *Peterson First Guide to Astronomy.* 1988, Houghton Mifflin. A brief pocket-size primer.

Pasachoff, J. & Menzel, D. *A Field Guide to the Stars and Planets, 3rd ed.* 1992, Houghton-Mifflin. One of the best pocket observing guides, with much information and detailed sky charts.

Reddy, F. & Walz-Chojnacki, G. *Celestial Delights.* 1992, Celestial Arts. Lists events in the night sky from 1993-2001, with good background information.

- Rey, H. A. *The Stars: A New Way to See Them.* 1967, Houghton Mifflin. A classic guide to the constellations that introduced a simplified way to keep track of them; one of the very best books for beginners. (First issued in 1952.)

Ridpath, I. & Tirion, W. *The Universe Guide to Stars and Planets.* 1985, Universe Books. A fine handbook for the novice with clear sky maps for both the northern and southern hemispheres.

- Whitney, C. *Whitney's Star Finder, 5th ed.* 1989, Random House. Excellent paperbound guide for beginners, with clear text and figures, by a Harvard astronomer.

Basic Guides: Not in Book Form

Abrams Planetarium: *Sky Calendar.* An extremely well-thought-out monthly calendar and star chart from the planetarium at Michigan State University. Available by subscription or in *Mercury* and *Science & Children* magazines.

- Astronomical Society of the Pacific: *Tapes of the Night Sky.* Two audio cassettes that familiarize the listener with the stars and constellations of each season; comes with star maps and full transcripts (see address in the list of organizations).

- Chandler, D. *Night Sky Star Dial* (available from Sky Publishing). This is perhaps the best of the many cardboard or plastic star wheels that can show you the stars visible on any night at your latitude. It is two-sided to minimize distortion and inexpensive.

Astronomy 101 (a 25-min video from the Astronomical Society of the Pacific) An 11-year old girl and her mom discover the basics of observing the night sky.

Norton, O. *Star Maps Constellations Slide Set* (set of 40 slides from the Astronomical Society of the Pacific) Carefully drawn star maps of each major constellation.

Sky Challenger. A series of star wheels and activities for students (and teachers) to help explore the constellations. (Write to: Discovery Corner, Lawrence Hall of Science, U. of California, Berkeley, CA 94720.)

More Advanced Observing Aids (Selected List)

Bishop, R., ed. *The Observer's Handbook.* Annual volume; Royal Astronomical Society of Canada (136 Dupont St., Toronto ON M5R 2V2, Canada). The standard North American reference book for keeping track of sky events; also has many useful tables of astronomical information.

Burnham, R. *Burnham's Celestial Handbook.* 1978, Dover Books. A mammoth 2,138-page (3 volume) guide to objects of all kinds that can be found with the naked eye and telescopes.

Cox, J. & Monkhouse, C. *Philip's Color Star Atlas, Epoch 2000.* 1990, Kalmbach. A good atlas for beginning stargazers.

Dickinson, T. & Dyer, A. *The Backyard Astronomer.* 1991, Camden House. A well-thought-out, rich guide by two experienced observers and astronomy writers.

Hirshfeld, A., et al. *Sky Catalogue 2000.0, 2nd ed.* 1994, Sky Publishing & Cambridge U. Press. Also available on disk. A companion to Sky Atlas 2000 (see below), this massive tabulation of information on 50,000 stars and thousands of other objects (in 2 volumes) is an invaluable reference for those who are serious observers of the sky.

Newton, J. & Teece, P. *The Guide to Amateur Astronomy, 2nd ed.* 1994, Cambridge U. Press. Practical advice for serious observing projects.

Ridpath, I. *Norton's 2000.0 Star Atlas and*

Reference Handbook. 1990, John Wiley. Revised updated edition of a classic atlas.

Sherrod, P. *A Complete Manual to Amateur Astronomy*. 1981, Prentice Hall. A good guide for those who want to move from simple stargazing to more extensive projects in amateur astronomy.

Tirion, W. *Sky Atlas 2000.0*. 1981, Sky Publ. & Cambridge U. Press. The best modern sky atlas for serious observers; includes 43,000 stars and 2,200 deep-sky objects.

SELECTED RESOURCES FOR STUDENTS

Asimov, I. & Reddy, F. *A Stargazer's Guide*. 1995, Gareth Stevens. Introduces the sky for each season and more.

Reddy, F. "Make a Starfinder" in *Odyssey*, Apr. 1991, p. 19.

Rey, H. *Find the Constellations*. 1976, Houghton Mifflin. Delightful book for both elementary and middle school students, with superb diagrams. One of the classic astronomy books; a simpler version of *The Stars: A New Way to See Them*, listed above.

Schatz, D. *Astronomy Activity Book*. 1991, Simon & Schuster. Superb activities for families to get acquainted with the sky and the objects in it.

Apfel, N. "The Sky from Down Under" in *Odyssey*, Feb. 1990, p. 14. What the moon and constellations look like in the Southern Hemisphere.

Barrett, N. *Night Sky*. 1985, Franklin Watts. For grades 4-6; introduction to different objects you can see in the sky.

Branley, F. *Sundogs and Shooting Stars: A Skywatcher's Calendar*. 1980, Houghton Mifflin. An interesting combination of monthly sky information, observing activities, historical anecdotes, and astronomy explanations.

Hatchett, C. *Glow in the Dark Night Sky Book*. 1988, Random House.

Hunig, K. *Astro-Dome: 3-D Maps of the Sky*. 1983, Sunstone. Cut-out book that lets you make a sky-dome.

Jobb, J. *The Night Sky Book*. 1979, Little Brown. Zany but informative book on constellations, the moon and the planets, full of activities and things to build.

Levitt, I. & Marshall, R. *Star Maps for Beginners*. 1987, Simon & Schuster. Monthly sky maps and sky information; grades 6 and up.

Ottewell, G. *To Know the Stars*. 1984, Astronomical Workshop, Furman University, Greenville, SC 29613. An introduction for older students to sky phenomena.

Pearce, Q. *Stargazer's Guide to the Galaxy*. 1991, Tom Doherty Associates. Star maps, constellations, a detachable star wheel; for grades 4-6.

Whitney's Star Finder, listed in the first section, is also an excellent primer for older students.

G

STARS

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ACTIVITIES INCLUDED IN STARS

ACTIVITY	ESTIMATED GRADE LEVEL											
Grades	1	2	3	4	5	6	7	8	9	10	11	12
G-1. Compare the Sizes of Stars Students cut out paper circles and use them to visualize the tremendous range of sizes of stars, compared with our Sun.			▨	■	■	■	▨	▨	▨			
G-2. Among the Stars Students use special cards, each with detailed information about a specific star, to order themselves in the classroom according to different stellar properties.				■	■	■	■	■	■	▨	▨	▨
G-3. Investigating Types of Stars Students use a radiometer to explore how the temperature, color and intensity of a light source are related, and apply the results to stars of different types.							■	■	■	▨	▨	▨

■ - Grade levels recommended by authors ▨ - Can be extended to these grade levels.

About the Activities:
Stars

Planetary Nebula

KEY IDEAS IN "STARS"

- Educational research shows that even in high school, many students are not aware that stars are distant Suns.
- It wasn't until the nineteenth century that astronomical instruments were sufficiently well developed to show that stars are distributed throughout space.
- The *Benchmarks* recommends that at the 3-5 grade level students should have direct experiences with lights at different distances, and be aware that the stars are Suns, but so far away that they look like points of light.
- By the end of eighth grade, students should know that light from the Sun takes a few minutes to reach the earth, but light from stars takes years to arrive.
- By the end of twelfth grade, students should know that stars differ from each other in size, temperature, and age, but they appear to be made up of the same elements; and that most are in orbiting systems of two or more stars.

Educational research shows that even in high school, many students are not aware that stars are distant Suns. Although they may have been told this at some point in time, it is hard to remember because it seems so unreasonable. After all, how could such tiny cold points of light be the same thing as the huge, hot Sun?

Historically, the idea that our Sun is a star—and not such a special star at that—has been slow to develop. Even Copernicus, whom we credit with introducing the modern view that the Earth revolves around the Sun, believed that our Sun was a special body, located at the center of the universe. Again, this is not surprising since even large telescopes cannot magnify enough to show the disks of stars; they still appear as points of light. It wasn't until the nineteenth century that astronomical instruments were sufficiently well developed to show that stars are distributed throughout space, by measuring the tiny shift in the positions of nearby stars as the Earth revolves around the Sun.

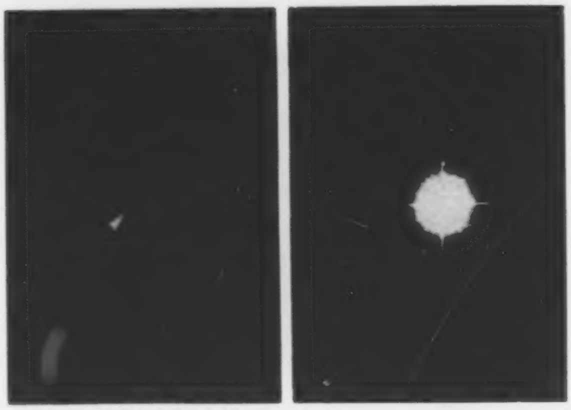
The *Benchmarks for Science Literacy* recommends that at the 3-5 grade level students should have an opportunity to experience "that a large light source at a great distance looks like a small light source that is much closer" and that by the end of fifth grade, students should know that "Stars are like the Sun, some being smaller and some larger, but so far away that they look like points of light." (*Benchmarks*, page 63.)

At the 6-8 level, "Finding distances by triangulation and scale drawings will help students to understand how the distances to the Moon and Sun were estimated and why the stars must be very much farther away. (The dependence of apparent size on distance can be used to pose the historically important puzzle that star patterns do not appear any larger from one season to the next, even though the Earth swings a hundred million miles closer to them.)" (*Benchmarks*, page 63.) And by the end of eighth grade, students should know that "The Sun is many thousands of times closer to the Earth than any other star. Light from the Sun takes a few minutes to reach the Earth, but light from the next nearest star takes a few years to arrive. The trip to that star would take the fastest rocket thousands of years." (*Benchmarks*, page 64.)

By the end of 12th grade, the *Benchmarks* recommends that "Students should know that...The stars differ from each other in size, temperature, and age, but they appear to be made up of the same elements that are found on the Earth and to behave according to the same physical principles. Unlike the Sun, most stars are in systems of two or more stars orbiting around one another." (*Benchmarks*, page 65.)

This section includes activities on the Sun as a star, the types and sizes of stars, star formation, and the distances to stars. Thematically, these activities relate to the broader ideas of scale and structure. You may want to start with activities about the scale of the solar system, and then present activities on the sizes and distances to stars, thus leading your students to understand the universe at larger and larger scales. You can also link these activities to subsequent sections on galaxies and the universe, emphasizing the composition, structures, and relative sizes of the structures in the known universe.

BACKGROUND: STARS



Supernova 1987A (Before & After)

Stars are giant balls of hot gas. They're also a lot like people. They're born, live through a long middle age, and, ultimately, die. They come in different sizes and colors. Many spend their lives with constant companions; others, like our Sun, go it alone. And, like people, stars change as they age. But because the changes take place over millions and billions of years, an individual star looks pretty much the same over the course of many human lifetimes. A photograph of the night sky, however, like a picture taken in a mall that shows people of all ages, can capture stars in different stages of their lives. Careful study of the differences we see in stars has given astronomers a sense of what goes on inside stars and how they change with time.

Stars come in different sizes. The Sun is actually a bit on the small side, when compared to its stellar cousins; as such, it is known as a dwarf star. The largest stars can have hundreds and even a thousand times the diameter of the Sun; not surprisingly, they're known as giant and supergiant stars. The smallest stars are not much bigger than the planet Jupiter. Stars also appear different colors, depending on the temperature at the star's gaseous surface. The coolest stars are nearly 5000 degrees Fahrenheit (about the same temperature as the filaments in incandescent lightbulbs), while the hottest stars reach a sweltering 90,000 degrees Fahrenheit! Cool stars appear red; hot stars are bluish-white. The constellation of Orion the Hunter, easily visible even in cities during the winter, is a perfect place to look for star colors. Betelgeuse, the bright star that represents Orion's right shoulder, shines bright red. Looking down toward the Hunter's left knee, you find another bright star, Rigel, which sparkles with a bluish-white color.

All the stars in the sky (including our Sun) are moving through space, most with speeds of many kilometers per second, although it may not seem that way to us. When we look at the night sky, we see basically the same star patterns as the ancients did. That's because the stars are so very, very far away that their motions appear tiny to us, even over the course of hundreds and thousands of years of watching.

Stars are born out of the huge clouds of gas and dust that fill some of the space between the stars. Occasionally, the densest parts of these reservoirs of cosmic "raw material" become unstable and begin to contract, the force of gravity pulling each atom toward the center. As the cloud continues to shrink, gas in the center gets denser and heats up. Temperatures and pressures build until they finally become so high that hydrogen atoms are forced to "fuse" together, with four hydrogen atoms becoming one helium atom [stars are almost all hydrogen

(92%); the rest is helium, with trace amounts of other elements]. This process is known as hydrogen fusion (note that the same thing happens in the warhead of a nuclear bomb). Fusion liberates an enormous amount of energy. Fusion energy creates a pressure that balances the weight of the star's upper layers, halting the contraction. The star then shines steadily, powered by the hydrogen fusion in its center, as it enters stellar middle age.

Our Sun is now about half way through its middle age. It has been "fusing" hydrogen in its center for about 5 billion years, and will continue to do so for another 5 billion. How long a star lasts, from the initial contraction of a gas cloud to its final death throes, depends on how massive it is. The Sun is just an average star; stellar masses range from a hundred times that of the Sun to just under a tenth. Massive stars live fast and die young, cramming an entire lifetime into a few million years before they blow themselves to bits. Smaller stars live quietly for tens and hundreds of billions of years and die much less spectacularly.

All stars, regardless of mass, eventually run out of hydrogen "fuel" in their centers. They begin to die. No longer able to support the weight of their outer layers, their cores contract, increasing central temperatures until helium atoms fuse together to form carbon ones. As before, energy released during the fusion halts the contraction and the star temporarily regains some measure of stability. In the meantime, the outer layers swell and cool, dramatically increasing the diameter of the star; during this so-called "red giant" phase, the Sun will expand out past the Earth's orbit (bad news for any Earthlings still around). What happens next depends on the star's mass.

When they finally run out of helium fuel in the center, stars like the Sun (and less massive ones too) are truly facing the grave. The core collapses under the tremendous weight of the star. The outer layers are gently ejected away from the star, exposing the core to space. When the core finally stops contracting, its material is so densely packed that a single teaspoonful would weigh over 15 tons! This stellar remnant is called a white dwarf. It initially glows from heat left over from the contraction and from billions of years of nuclear fusion. But, with no new source of energy, the stellar corpse gradually cools and slowly fades from sight, a stellar ember feebly glowing in the cosmic fireplace.

Stars more massive than the Sun do not exit so gently. When they've exhausted their helium reserves, they too begin to contract. However, compression from their tremendous weight allows additional elements to fuse together in their centers (for example, carbon fuses to become neon), releasing energy and halting the contraction, giving the stars a series of temporary reprieves. But, ultimately, fusion stops and nothing can stop the inevitable core collapse. This time, the collapse is accompanied by an explosive ejection of the outer layers—a supernova explosion—that literally tears the star apart.

In the meantime, the core shrinks dramatically. If, after the supernova explosion, the leftover mass is about 2-3 times that of the Sun, the core collapses until its material is so densely packed that a sugar-cube-sized lump weighs 100 million tons! The remnant is called a neutron star because it consists mostly of super-compressed neutrons. If the post-supernova mass is higher still, no force in nature can stop the collapse. The core shrinks and shrinks and shrinks, until, finally, all its mass is crunched into something with zero diameter and infinite density! It is a black hole; black in the sense that nothing—not even light—can escape from it, and a hole in the sense that things can fall in, but they can't get back out.

Massive stars may lead more interesting lives than those like the Sun, but there aren't very many of them. Most stars, in fact, have even smaller masses than the Sun. Something in the process of star formation seems to favor the creation of a lot of smaller stars over that of a few large ones. Perhaps half of all stars form in pairs, with two (and sometime more) stars bound together by their mutual gravitational attraction. These travel through space together, caught in a kind of cosmic square-dance as they orbit around one another.

Despite all we now know about stars and their lives, perhaps the most surprising thing we have learned is that, without stars, we wouldn't be here. Indications are that the cosmos began with only hydrogen and helium, from which it would not have been possible to construct anything as interesting as one of our students. Nearly all the atoms in our bodies, and in our chairs, our gardens, our cars, and in nearly everything we see around us, originated in the centers of massive stars. The atoms were originally "cooked" in the nuclear fires deep inside these stars. Then, when these stars exploded at the end of their lives, the newly created atoms were thrown out into interstellar space. There they gathered together, forming new clouds of gas and dust, which ultimately contracted as new stars were born. Some of the atoms made their way into the planets that circled one particular new star, and eventually into the life that sprang up on the one called Earth. We are truly star stuff.

COMPARE THE SIZES OF STARS

ACTIVITY G-1

GRADE LEVEL: 4-6+

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What's This Activity About?

We only have one star to study in detail—our Sun. We can measure its size with geometry, knowing the average Earth-Sun distance. But how does our Sun compare with other stars? All are so far away that they appear as points, no matter what their size. Using spectroscopy, astronomers can classify stars and determine their diameters, even though we cannot measure their sizes in a telescope or photo.

Stellar sizes vary tremendously, and this simple scaling activity can help students to visualize the great differences between the smallest stellar "corpse," a neutron star, and the largest stellar supergiant.

What Will Students Do?

Students cut out paper circles to model the approximate sizes of a variety of stars, based on the size of our Sun. Different colored paper can be used to reflect the stars' actual colors.

Tips and Suggestions

- Based on the Sun's diameter scaled to a 5 cm paper circle, the nearest star would be almost 1500 km away (about 900 miles). Stars are infinitesimal when compared to their average separation.
- The activity also does not explain why stars are different sizes, or how they evolve from one type to another. These topics relate to stellar evolution. (For more, see the readings on the resource list at the end of this section.)
- This activity can be linked to "Spectroscopes" in *Tools of the Astronomer*.

What Will Students Learn?

Concepts
Stellar diameters
Scale of space

Inquiry Skills
Comparing
Ordering

Big Ideas
Models

EXPERIMENT 46

COMPARE THE SIZES OF STARS

Most people don't realize that stars are vastly different in size. Study the following list to see just how large the difference can be.

STAR	SIZE
Sun	1 solar diameter
Rigel	50 solar diameters
Betelgeuse	550 solar diameters
Aldebaran	36 solar diameters
Castor A	2 solar diameters
Jupiter	0.1 solar diameter
White Dwarf	0.01 solar diameter
Neutron Star	0.00001 solar diameters

Figure 35

Star size is measured by comparing it to the sun. The sun has a size of 1 solar diameter. A star that is twice as big would have a size of 2 solar diameters. Because of the large size of some of the stars, make your model flat instead of 3d. Paper is the best material to use.

Making a model of the different sizes of stars can be very informative, but it can be difficult. For example, if you make the sun 1 foot across, then Betelgeuse would have a diameter of almost two football fields! (That's a lot of paper to cut out!) Even at this size, a Neutron star would be only a thousandth of an inch across. The best strategy is to construct the middle size stars and describe those that are very big or very small.

Make the Sun about 5 cm across. Cut it out of yellow construction paper, since it is a yellow star. To determined the size of the other stars, multiply their diameter by the scale size of one solar diameter, (5 cm.) For example Castor B has a size of 2 solar diameters. This means that your model would be 10 cm across.

To make the big stars like Rigel, use colored butcher paper.[18] You may have to tape two or three lengths together to make a large enough piece. Use masking tape and apply it to the back of the paper so it doesn't show. A string cut to the length of the radius of the star can act as an oversized compass.

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[18] It can be purchased form a teacher supply store or a paper company. You teacher may even be able to obtain some from the school's supply.

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Betelgeuse will be so large that you can't make a full model. You can describe how large it would be, by comparing it to something familiar. Or else you can only construct part of the star: Get about 6 feet of red butcher paper and the correct length of string. You will need to make a compass that is 13.75 meters long. Use this string to mark an arc on the butcher paper. Cut out only this arc and display it near the other stars.

You may be able to cut out Jupiter, but it will only be 5 mm across. (A paper cutout from a hole punch is close enough to the correct size.) A White Dwarf and Neutron stars would be too small to build. Again, describe their size by comparing them to familiar objects.

To display these stars, request a location at the science fair next to a wall. Hang Rigel on the wall first. Then glue or tape the other stars on to it. Place them in the very center, so they look like the different rings of a target. On the table place another larger model of the sun, with Jupiter inside of it.

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AMONG THE STARS

ACTIVITY G-2

GRADE LEVEL: 4-9

Source: Reprinted by permission from *Adler Planetarium Star Cards Lesson Plan: Among the Stars of Winter*, by Vivian Hoette. Copyright ©1995 by Vivian Hoette. Available from the Adler Planetarium, 1300 Lakeshore Drive, Chicago, IL 60605, (312) 322-0549.

What's This Activity About?

Stars reveal their secrets grudgingly. With our eyes alone, we can observe that stars vary in apparent brightness, and that they have slightly different colors. But spectroscopy and the laws of physics allow scientists to determine or estimate much more about stars. From characteristic patterns of gas absorption lines in the star's light, we can tell its surface temperature and its general type (dwarf, giant, supergiant). By measuring the slight changes in the position of nearby stars relative to much more distant ones as our planet orbits the Sun, we determine the distances of those nearby neighbors. Like the first rungs of a ladder, those distances and temperatures allow astronomers to determine the properties of more distant stars. From the orbital motions of multiple star systems, we can determine stellar masses and develop theories about stellar evolution.

This activity will help students to learn how stars can be classified in many different ways. Participants enjoy role-playing as their favorite stars, and the activity's real strength comes from letting the students come up with different ways to classify themselves.

What Will Students Do?

Each student examines a *star card*, which includes information about a particular star's spectral type, distance, temperature, size, and constellation. Students first form groups based on the constellations and then order themselves according to characteristics. For example, the class could line up by temperature, with the coolest stars at one end and the hottest stars at another. The students can decide which characteristics to use to create their organization.

Tips and Suggestions

- You can create additional cards using the data provided, or have students create them.
- It is important to relate how science is used to determine the many characteristics shown on each card. Tie this activity to those in the *Tools of the Astronomer* section.
- Encourage students to find their star in the night sky by using the Star Finder from the *Star Finding and Constellations* section.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Stellar properties	Classifying Comparing Ordering Organizing	Diversity and Unity

Among the Stars of Winter

Star Cards and Lesson Plan by Vivian Hoette

LEVEL Third through tenth grade students.

INSTRUCTIONAL ARRANGEMENT There should be open space (a hallway or an open area in the classroom, etc.) for students to form groups or lines.

RATIONALE Personalizing star information allows students to understand physical characteristics of stars in a familiar way, associating individual stars with members of the student group and sorting stars while sorting the people who have the information about those stars on cards.

LENGTH Twenty minutes or more depending on teacher's objectives and students' interests. Star cards may be used on several occasions or with different grade levels depending on lesson objectives.

OBJECTIVES

- Students will learn that stars vary in: color, brightness, true size and luminosity, distance from Earth, temperature, etc. Stars are identified by their place within a constellation pattern.
- Students will learn that the peak color in a star's light is related to the star's surface temperature.
- Students will learn that most of the stars we see in the night sky are bigger and brighter than the sun.
- Using star data as a source of comparison and classification, students will practice classification, ordering, and application of numerical skills involving positive and negative numbers, the number line, decimals to the hundredth place, and number names up to hundreds of thousands.
- Students will become familiar with star and constellation names and historic constellation figures.

MATERIALS and PREPARATION

1. Cut apart the star cards of the forty or so named stars belonging to constellations of the Winter Circle (Orion, Lepus, Canis Major, Canis Minor, Gemini, Auriga, and Taurus).
2. Mount the cards on red, orange, yellow, white, blue-white, or blue construction paper to match the peak color of each star's spectrum. Laminate the cards.
3. Use a marker to write the name of the star and its constellation in large letters on the back of the card. Use uppercase for the first letter and lower case for the remaining letters of the star's name. Use all uppercase for the name of the constellation.

PROCEDURE

Engage Student Interest

- Ask students to observe the night sky on a clear evening or view constellation slides in class. Invite the students to sketch, share and discuss their observations.
- Randomly drop stars of different colors and sizes onto dark construction paper. Ask students to glue down the stars, create drawings around them, and tell or write stories about the drawings.

Allow Students to Explore and Classify Stars

1. Let students select a particular star card or pass cards out randomly. (Some teachers use the cards as basis for cooperative group arrangements.)
2. Ask students to study the information on the cards. Give them time to look over the cards and compare the information on their card with information on the cards of their classmates.
3. Ask the group if anyone has an idea about how these stars could be organized. (As we look at the stars in the night sky, they seem 'stuck' in their constellations. In this activity students are able to arrange and rearrange stars according to their apparent and physical properties.)
4. As different ideas are suggested, encourage the person who presented the idea to organize the people in the class (each being a different star) to form groups or lines illustrating the plan suggested. Encourage student leadership.

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Explain Astronomy Concepts

Discuss the astronomy concepts and content of the various data fields presented on the cards as students suggest ways to organize the stars.

Star Names: The names of stars are very old. Meanings that do not make sense when looking at the constellation drawings may give clues to the origination of names from earlier cultures who have imagined different pictures in the stars and told different stories. Often star names refer to significant rising and setting times, seasonal and meteorological events, as well as to imaginary figures.

Identification: On constellation drawings, brighter stars are identified by Greek letters assigned by Johann Bayer in 1601. These stars are identified by the Greek letter and the constellation name in the Latin genitive case; this identification is given in its abbreviated and entire form.

Distance: Distance in space is measured in light-years. One **light-year** is the distance light travels in a year, about 9.5 trillion kilometers or about 6 trillion miles.

Peak Color: Starlight is studied by spectroscopy (using diffraction to break light into its component colors). Depending on how hot a star is, the light emitted from the star shines brightest in certain wavelengths. Stars whose spectra peak in the red are cooler than stars whose spectra peak in the blue.

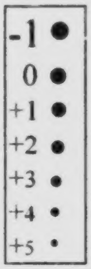
Temperature in Kelvins: This is the surface temperature of the star. When one organizes the stars by surface temperature, one also sees the relationship of peak color to temperature.

Astronomers use the Kelvin scale. Scale changes in Kelvin (K) are equivalent to those in Celsius; the difference is the placement of zero. Absolute zero in Kelvin is 0 K; absolute zero in Celsius is -273.150 degrees. Freezing in Kelvin is 273.150 K; freezing in Celsius is 0 degrees. Boiling in Kelvin is 373.150 K; boiling in Celsius is 100 degrees. One reads the temperature in the Kelvin scale as so many Kelvins rather than using the word degrees as with the Celsius or Fahrenheit scales.

Star's Class (called Luminosity Class by astronomers): The stage of the star's 'life' cycle. Most stars spend most of their existence in the main sequence phase. Later, stars enlarge dramatically to become giant or supergiant stars. Finally, most stars shrink to become white, red, or black dwarfs. Some stars explode as supernovae while their cores collapse into extremely dense neutron stars or black holes.

Diameter: Width of the star, as compared to the sun.

Luminosity: Total light energy emitted by the star, as compared to the sun.



Magnitude Scales: A measure of the brightness of a star. The magnitude scale is logarithmic (2.5 times the brightness between consecutive numbers). Our eyes see light logarithmically. Magnitudes describe brightness inversely so that smaller numbers indicate brighter stars; zero and negative numbers indicate still greater brightness.

Apparent Magnitude: How bright the star appears or seems to be as we observe it from Earth. The system was first set up ages ago with a scale of one to six. One was for the brightest stars and six was for the faintest stars that people could see. Since that time, we have been able to measure the brightness of stars more accurately. The apparent magnitude scale now extends to zero and negative numbers for the very brightest stars.

Absolute Magnitude: True or intrinsic brightness of a star; this scale measures the stars as if they were all the same distance away (about 32.6 light years).

Spectral Type: Spectral classifications are O, B, A, F, G, K, and M. O stars are the hottest and M stars are the coolest. Luminosity class is indicated by Roman numerals. I is supergiant: II is bright giant; III is giant; IV is subgiant; and V is main sequence. Spectral and luminosity classes are further subdivided with numbers and letters.

Constellation Drawings: The drawings of Auriga, Canis Major, Canis Minor, Gemini, and Orion are adapted from Johann Bode, 1801. The drawing of Taurus is adapted from John Bevis (based on Bayer), 1750. The drawing of Lepus is adapted from Pardies.

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Enhance Student Interest

- Plan a field trip for your students to the Adler Planetarium or a planetarium near your school.
- Arrange to bring a portable planetarium to your school.
- Plan a star party inviting an amateur astronomer to bring a telescope to your school in the evening.
- Use diffraction gratings or prisms to analyze various sources of light.
- Visit the library to find books on astronomy and constellations. Research constellation stories.

Evaluate Students' Understanding.

- Give individuals or small groups of students a subset of the star cards and ask them to organize and group the stars by various criteria. Ask students to explain their classification systems.
- Ask individuals or groups to brainstorm all the ways stars are different from each other and the ways stars are alike. Do this as both a pre and post evaluation of students' ideas about stars.
- Use the **KWL** (Know?, Want to know? Learned?) method. What do you already know about stars? What do you want to know about stars? as questions to pose to students before the activity. After the activity ask students to write or discuss what they have learned about stars.

ABOUT THE DATABASE

The physical star data used for this set of cards was drawn from StarList 2000 by Richard Dibon-Smith who also provided updated data regarding Alnitak, Betelgeuse, Mebsuta, and Saiph. The temperature values were determined by the author using a variety of methods. Star data varies widely depending on the reference work one is using. Conflicting data results as astronomers learn more about stars, refer to different data sets or use different methods of analyzing data. The author accepts full responsibility for errors not accounted for by the range of values found in the available astronomical reference works.

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Among the Stars of Winter Database

Star Name	Pronunciation Key	Abbreviated Identification	Greek Letter Name + Constellation Genitive	Distance in Light-years	Peak Color in Spectrum
Capella	kah-PELL-ah	α Aur	Alpha Aurigae	44	yellow
Menkalinan	men-CALL-ih-nan	β Aur	Beta Aurigae	80	blue-white
Almaaz	al-MAAZ	ε Aur	Epsilon Aurigae	6,500	white
Hoedus II	HEE-dus 2	η Aur	Eta Aurigae	310	blue
Hassaleh	hah-SAW-leh	ι Aur	Iota Aurigae	330	orange
Theta Auriga	THAY-tah Auriga	θ Aur	Theta Aurigae	150	blue-white
Hoedus I	HEE-dus 1	ζ Aur	Zeta Aurigae	530	orange
Sirius	SEAR-eh-us	α CMa	Alpha Canis Majoris	9	blue-white
Mirzam	MERE-zam	β CMa	Beta Canis Majoris	740	blue
Wezen	WE-zen	δ CMa	Delta Canis Majoris	3,100	white
Adhara	a-DAY-rah	ε CMa	Epsilon Canis Majoris	490	blue
Muliphen	moo-li-FAYN	γ CMa	Gamma Canis Majoris	1,000	blue
Aludra	ah-LUD-rah	η CMa	Eta Canis Majoris	2,500	blue
Furud	FOU-rude	ζ CMa	Zeta Canis Majoris	290	blue
Procyon	PRO-seh-on	α CMi	Alpha Canis Minoris	11	white
Gomeisa	go-MY-za	β CMi	Beta Canis Minoris	140	blue
Castor	CASS-ter	α Gem	Alpha Geminorum	47	blue-white
Pollux	PAUL-lucks	β Gem	Beta Geminorum	35	orange
Wasat	WAY-sat	δ Gem	Delta Geminorum	53	white
Mebsuta	meb-SUE-tah	ε Gem	Epsilon Geminorum	190	yellow
Alhena	al-HEN-ah	γ Gem	Gamma Geminorum	88	blue-white
Propus	PRO-puss	η Gem	Eta Geminorum	190	red
Tejat Posterior	TAY-got posterior	μ Gem	Mu Geminorum	160	red
Alzirr	al-ZEER	ξ Gem	Xi Geminorum	59	white
Mekbuda	mek-BOO-dah	ζ Gem	Zeta Geminorum	1,500	yellow
Arneb	ARE-neb	α Lep	Alpha Leporis	930	white
Nihal	HIGH-al	β Lep	Beta Leporis	320	yellow
Betelgeuse	BET-el-jooz	α Ori	Alpha Orionis	325	red
Rigel	RYE-jel	β Ori	Beta Orionis	910	blue
Mintaka	min-TAH-kah	δ Ori	Delta Orionis	2,300	blue
Alnilam	al-NIGH-lam	ε Ori	Epsilon Orionis	1,200	blue
Bellatrix	beh-LAY-trix	γ Ori	Gamma Orionis	360	blue
Algiebba	al-GABE-bah	η Ori	Eta Orionis	770	blue
Nair al Saif	NAIR al-SIGH-f	ι Ori	Iota Orionis	1,900	blue
Saiph	SAFE	κ Ori	Kappa Orionis	215	blue
Meissa	my-SAH	λ Ori	Lambda Orionis	470	blue
Alnitak	al-NIGH-tak	ζ Ori	Zeta Orionis	1,600	blue
Aldebaran	al-DEB-ah-ran	α Tau	Alpha Tauri	65	orange
El Nath	EL-nath	β Tau	Beta Tauri	150	blue
Ain	EYE-n	ε Tau	Epsilon Tauri	150	yellow
Al Hecka	al-HECK-a	ζ Tau	Zeta Tauri	520	blue
Alcyone	al-SIGH-oh-nee	η Tau	Eta Tauri	260	blue
Sun		Distance from Earth is 8.3 light-minutes			yellow

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Among the Stars of Winter Database

Star Name	Greek Letter	Star's Luminosity Class	Temperature in Kelvins (K)	Diameter in Suns	Luminosity in Suns	Apparent Magnitude	Absolute Magnitude	Spectral Type
Capella	α	giant	5,100	11	72	0.08	0.09	G8 III
Menkalinan	β	subgiant	9,000	2	45	1.90 variable	0.6	A2 IV
Almaaz	ε	supergiant	7,200	365	200,000	2.99 variable	-8.5	F0 Ia
Hoedus II	η	main sequence	21,000	3	377	3.17	-1.7	B3 V
Hassaleh	ι	bright giant	4,200	73	655	2.69	-2.3	K3 II
Theta Auriga	θ	peculiar	10,000	2	146	2.62 variable	-0.7	A0 pec
Hoedus I	ζ	bright giant	4,300	53	655	3.75 variable	-2.3	K4 II
Sirius	α	main sequence	9,700	2	21	-1.46	1.42	A1 V
Mirzam	β	bright giant	26,000	4	6,500	1.98 variable	-4.8	B1 II
Wezen	δ	supergiant	6,000	365	125,000	1.86	-8.0	F8 Ia
Adhara	ε	bright giant	20,000	5	4,500	1.50	-4.4	B2 II
Muliphen	γ	bright giant	14,000	5	1,803	4.11	-3.4	B8 II
Aludra	η	supergiant	14,500	37	50,000	2.44	-7.0	B5 Ia
Furud	ζ	main sequence	18,000	2	377	3.02	-1.7	B2.5 V
Procyon	α	subgiant	6,700	2	7	0.38	2.64	F5 IV
Gomeisa	β	main sequence	13,000	2	95	2.90 variable	-0.2	B8 Ve
Castor	α	main sequence	9,300	2	28	1.58	1.14	A1 V
Pollux	β	giant	4,900	9	32	1.14	0.98	K0 IIIb
Wasat	δ	subgiant	7,000	2	8	3.53	2.46	F2 IV
Mebsuta	ε	supergiant	5,000	33	175	2.98	-0.9	G8 Ib
Alhena	γ	subgiant	9,800	3	79	1.93	0	A0 IV
Propus	η	giant	3,100	34	125	3.28 variable	-0.5	M3 III
Tejat Posterior	μ	giant	2,900	35	125	2.88 variable	-0.5	M3 IIIa
Alzirr	ξ	giant	6,600	2	11	3.36	2.1	F5 III
Mekbuda	ζ	supergiant	5,700	86	5,000	3.79 variable	-4.5	G0 Ib
Arneb	α	supergiant	7,400	32	6,000	2.58	-4.7	F0 Ib
Nihal	β	bright giant	5,600	30	545	2.84	-2.1	G5 II
Betelgeuse	α	supergiant	3,400	265	5,000	0.50 variable	-4.5	M1 Iab
Rigel	β	supergiant	13,000	58	55,000	0.12	-7.1	B8 Iac
Mintaka	δ	giant	24,000	13	50,000	2.23 variable	-7.0	B0 III
Alnilam	ε	supergiant	23,000	16	25,000	1.70 variable	-6.2	B0 Iae
Bellatrix	γ	giant	23,000	3	2,168	1.64	-3.6	B2 III
Algiebba	η	main sequence	19,000	8	1,977	3.36 variable	-3.5	B1 V
Nair al Saif	ι	giant	28,000	6	20,000	2.77	-6.0	O9 III
Saiph	κ	supergiant	22,000	4	525	2.06	-2.1	B0.5 Ia
Meissa	λ	not indentified	35,000	3	552	3.66	-2.2	O8 e
Alnitak	ζ	supergiant	28,000	80	34,000	2.05	-6.6	O9.5 Ib
Aldebaran	α	giant	4,000	34	137	0.85 variable	-0.6	K5 III
El Nath	β	giant	14,000	2	344	1.65	-1.6	B7 III
Ain	ε	giant	5,000	13	65	3.53	0.2	G9.5III
Al Hecka	ζ	giant	18,000	4	1247	3.00	-3.0	B4 III
Alcyone	η	giant	15,000	3	344	2.87	-1.6	B7 III
Sun		main sequence	5,800	1	1	-26.72	4.74	G2 V

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Among the Stars of Winter Database

Star Name	Significance of Star Name
Capella	little she-goat, goat star, rainy goat star
Menkalinan	shoulder of the rein holder
Almaaz	he-goat; western goat star; signal for close of navigation; also called Al Anz
Hoedus II	one of kid goats, rising before Sun marks stormy season
Hassaleh	marks back of charioteer's knee
Theta Auriga	marks wrist of charioteer
Hoedus I	one of kid goats; rising before Sun marks stormy season; also called Sadatoni
Sirius	sparkling; dog star; scorching one; rising before Sun on hottest days of summer
Mirzam	roarer or announcer (of Sirius)
Wezen	weight; also called Wesen
Adhara	maiden, attendant of Suhail who married Orion
Muliphen	marks the top of the dog's head
Aludra	maiden, attendant of Suhail who married Orion
Furud	male apes, also called Phurud
Procyon	before the dog (rising before Sirius), water dog (near Milky Way)
Gomeisa	watery eyed (near Milky Way), also called Mirzam
Castor	horseman, mortal twin
Pollux	boxer, immortal twin
Wasat	middle of the sky (near the ecliptic)
Mebsuta	outstretched paw of the lion
Alhena	brand mark
Propus	the projecting foot; also called Tejat Prior
Tejat Posterior	heel
Alzirr	button
Mekbuda	folded paw of the lion
Arneb	the hare
Nihal	camels quenching their thirst
Betelgeuse	arm of central one; armpit of white belted sheep
Rigel	left leg of giant, Orion's left foot
Mintaka	belt
Alnilam	string of pearls
Bellatrix	Amazon female warrior
Algiebba	handle of the sword
Nair al Saif	bright one of the sword
Saiph	sword of powerful one
Meissa	glittering star
Alnitak	girdle
Aldebaran	follower (of the Pleiades)
El Nath	the one butting with horns
Ain	eye
Al Hecka	white one
Alcyone	brightest one of the Pleiades (Seven Sisters)

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Adler Planetarium Star Cards March, 1995

Star: Rigel *RYE-jel*
left leg of giant, Orion's left foot

Identification: β Ori *Beta Orionis*

Distance from Earth: 910 light-years

Peak Color: blue

Temperature in Kelvins: 13,000 K

Star's Class: supergiant

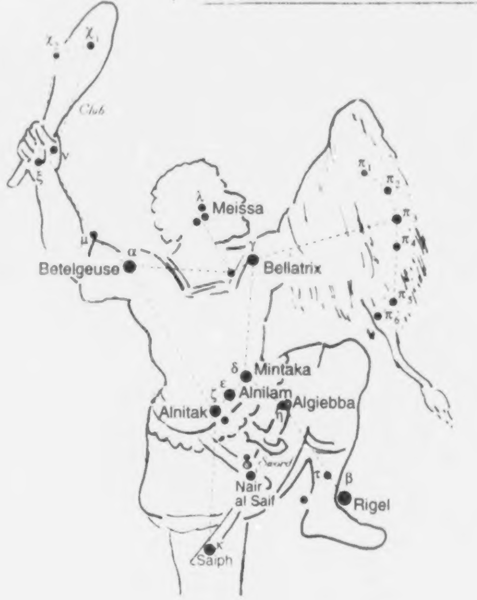
Diameter: 58 solar diameters

Luminosity: 55,000 times Sun's brightness

Apparent Magnitude: +0.12

Absolute Magnitude: -7.1

Spectral Type: B8 Iac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Alnilam
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Alnitak
Algiebba
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Sword
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β
Rigel
κ
Saiph

Constellation: ORION *oh-RYE-un* HUNTER

Adler Planetarium Star Cards March, 1995

Star: Arneb *ARE-neb*
the hare

Identification: α Lep *Alpha Leporis*

Distance from Earth: 930 light-years

Peak Color: white

Temperature in Kelvins: 7,400 K

Star's Class: supergiant

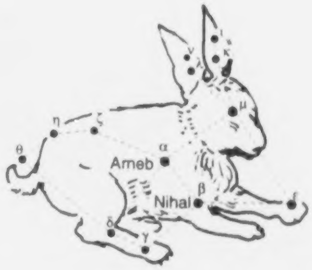
Diameter: 32 solar diameters

Luminosity: 6,000 times Sun's brightness

Apparent Magnitude: +2.58

Absolute Magnitude: -4.7

Spectral Type: F0 Ib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Constellation: LEPUS *LEE-puss* HARE

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Adler Planetarium Star Cards March, 1995

Star: **Procyon** *PRO-seh-on*
before the dog (rising before Sirius), water dog (near Milky Way)

Identification: α CMi *Alpha Canis Minoris*

Distance from Earth: 11 light-years

Peak Color: white

Temperature in Kelvins: 6,700 K

Star's Class: subgiant

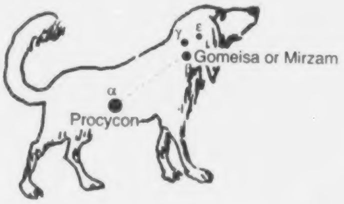
Diameter: 2 solar diameters

Luminosity: 7 times Sun's brightness

Apparent Magnitude: +0.38

Absolute Magnitude: +2.64

Spectral Type: F5 IV Constellation: **CANIS MINOR** *KAY-niss MY-ner* LITTLE DOG


γ
ε
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Adler Planetarium Star Cards March, 1995

Star: **Betelgeuse** *BET-el-jooz*
arm of central one; armpit of white belted sheep

Identification: α Ori *Alpha Orionis*

Distance from Earth: 325 light-years

Peak Color: red

Temperature in Kelvins: 3,400 K

Star's Class: supergiant

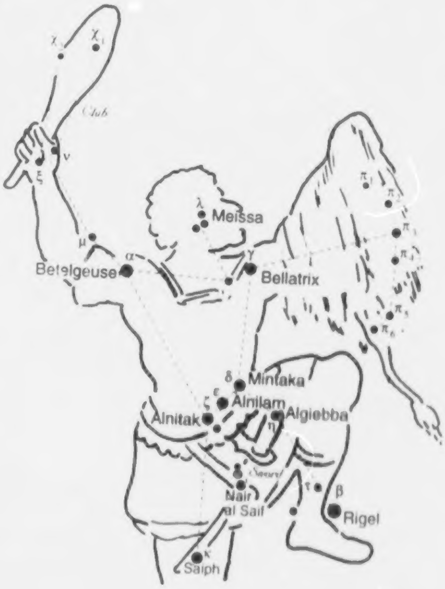
Diameter: 265 solar diameters

Luminosity: 5,000 times Sun's brightness

Apparent Magnitude: +0.50 variable

Absolute Magnitude: -4.5

Spectral Type: M1 Iab Constellation: **ORION** *oh-RYE-un* HUNTER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Adler Planetarium Star Cards March, 1995

Star: **Capella** *kah-PELL-ah*
little she-goat, goat star, rainy goat star

Identification: α Aur *Alpha Aurigae*

Distance from Earth: 44 light-years

Peak Color: yellow

Temperature in Kelvins: 5,100 K

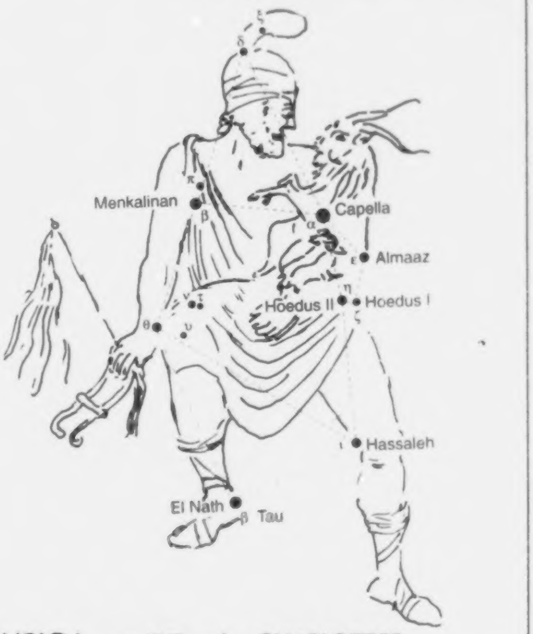
Star's Class: giant

Diameter: 11 solar diameters

Luminosity: 72 times Sun's brightness

Apparent Magnitude: +0.08

Absolute Magnitude: +0.09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Hassaleh
El Nath
β Tau

Spectral Type: G8 III Constellation: **AURIGA** *au-RYE-gah* **CHARIOTEER**

Adler Planetarium Star Cards March, 1995

Star: **Sirius** *SEAR-eh-us*
sparkling; dog star; scorching one; rising before Sun on hottest days of summer

Identification: α CMa *Alpha Canis Majoris*

Distance from Earth: 9 light-years

Peak Color: blue-white

Temperature in Kelvins: 9,700 K

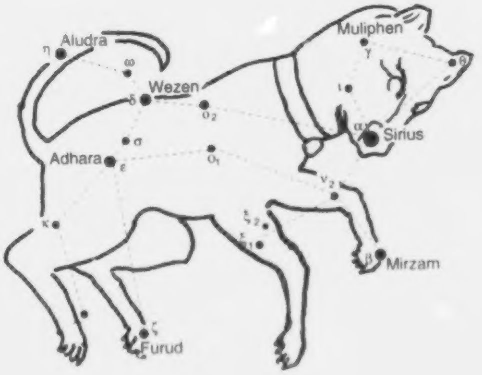
Star's Class: main sequence

Diameter: 2 solar diameters

Luminosity: 21 times Sun's brightness

Apparent Magnitude: -1.46

Absolute Magnitude: +1.42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Mirzam
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Furud

Spectral Type: A1 V Constellation: **CANIS MAJOR** *KAY-nis MAY-jer* **BIG DOG**

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Star: Aldebaran *al-DEB-ah-ran*
follower (of the Pleiades)

Identification: α Tau *Alpha Tauri*

Distance from Earth: 65 light-years

Peak Color: orange

Temperature in Kelvins: 4,000 K

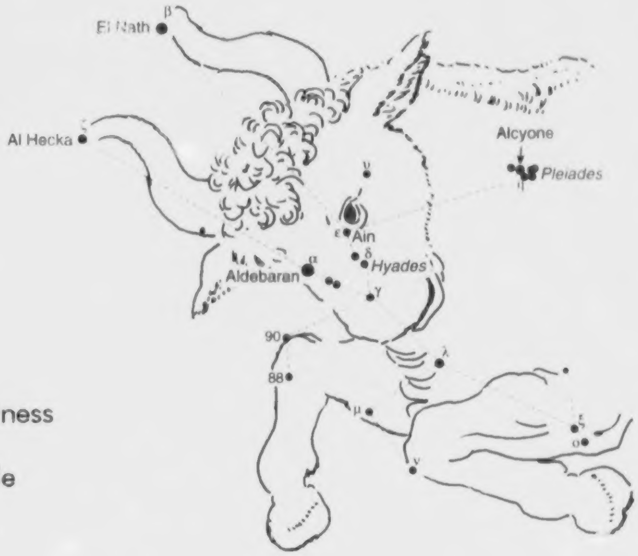
Star's Class: giant

Diameter: 34 solar diameters

Luminosity: 137 times Sun's brightness

Apparent Magnitude: +0.85 variable

Absolute Magnitude: -0.6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Spectral Type: K5 III   Constellation: **TAURUS** *TAW-russ* BULL

Adler Planetarium Star Cards March, 1995

Star: Castor *CASS-ter*
horseman, mortal twin

Identification: α Gem *Alpha Geminorum*

Distance from Earth: 47 light-years

Peak Color: blue-white

Temperature in Kelvins: 9,300 K

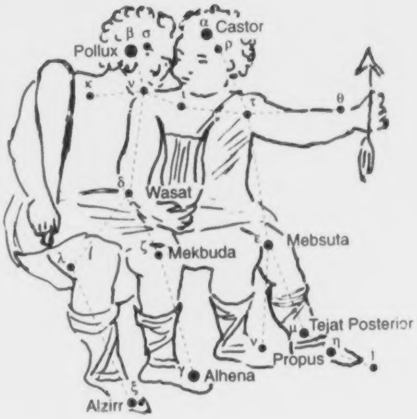
Star's Class: main sequence

Diameter: 2 solar diameters

Luminosity: 28 times Sun's brightness

Apparent Magnitude: +1.58

Absolute Magnitude: +1.14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Spectral Type: A1 V   Constellation: **GEMINI** *GEM-in-eye* TWINS

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Star: **Alnitak** *al-NIGH-tak*
girdle

Identification: ζ Ori *Zeta Orionis*

Distance from Earth: 1,600 light-years

Peak Color: blue

Temperature in Kelvins: 28,000 K

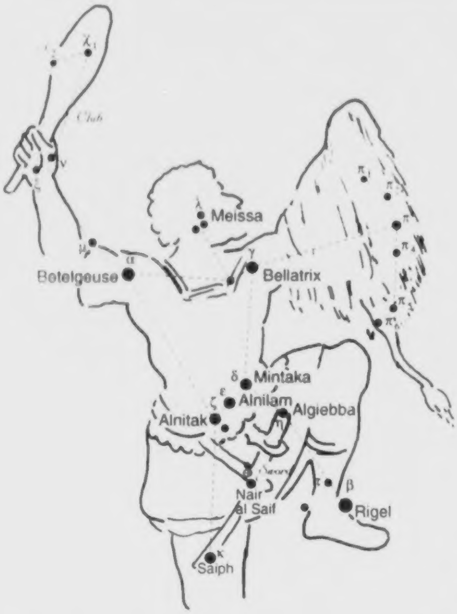
Star's Class: supergiant

Diameter: 80 solar diameters

Luminosity: 34,000 times Sun's brightness

Apparent Magnitude: +2.05

Absolute Magnitude: -6.6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Spectral Type: O9.5 Ib Constellation: **ORION** *oh-RYE-un* **HUNTER**

Adler Planetarium Star Cards March, 1995

Star: **Pollux** *PAUL-lucks*
boxer, immortal twin

Identification: β Gem *Beta Geminorum*

Distance from Earth: 35 light-years

Peak Color: orange

Temperature in Kelvins: 4,900 K

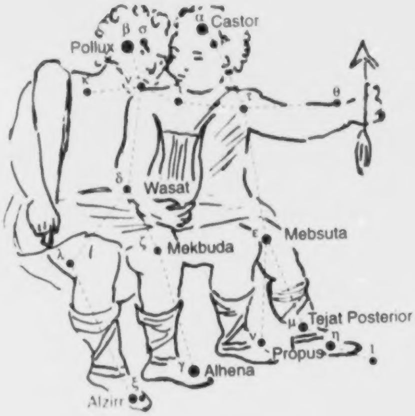
Star's Class: giant

Diameter: 9 solar diameters

Luminosity: 32 times Sun's brightness

Apparent Magnitude: +1.14

Absolute Magnitude: +0.98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Alzirr

Spectral Type: K0 IIIb Constellation: **GEMINI** *GEM-in-eye* **TWINS**

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Star:

Identification:

Distance from Earth: light-years

Peak Color:

Temperature in Kelvins: K

Star's Class:

Diameter: solar diameters

Luminosity: times Sun's brightness

Apparent Magnitude:

Absolute Magnitude:

Spectral Type: Constellation:

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INVESTIGATING TYPES OF STARS

ACTIVITY G-3

GRADE LEVEL: 7-9+

Source: Reprinted by permission from the "Investigating Types of Stars" lesson, adapted from *Evolution of a Planetary System*, Vol. 1 of the *SETI Academy Planet Project*. SETI Institute. Copyright ©1995 SETI Institute. Available from Teacher Ideas Press, Englewood, CO (800) 237-6124.

What's This Activity About?

This is a wonderful experiment to demonstrate how temperature, color, and intensity of light sources are related. The activity will help students to understand how astronomers can classify stars based on their colors, and it also illustrates how scientists can create a laboratory model to explore stellar properties. It includes excellent background information and good pre- and post-activity questions. The activity is part of the *SETI Academy Planet Project*, a three volume set of teaching kits from the *Life in the Universe Series* of curriculum guides.

What Will Students Do?

Students will experiment with a radiometer and a variable light source to measure intensities of three different light sources. (A radiometer indicates the pressure of light striking a black and white rotating vane.) Students will discover how a star's color is related to its surface temperature. From their experiments, students can infer how stars with different temperatures live very different lives, and affect their immediate surroundings in different ways.

Tips and Suggestions

- The activity is part of an integrated curriculum from the SETI institute, and approaches the experiment by asking which stars should be searched for planets with the possibility of intelligent life.
- The lesson could be done with activities about spectroscopy, or with the other activities included in the *Space Exploration and SETI* section.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Visible and infrared radiation	Experimenting	Energy Models
Radiation intensity	Measuring	
	Inferring	

Mission 4
Investigating Types of Stars

Is Our Sun Unique?

Overview

In Mission 3, the students did an experiment in which they simulated the formation of our Solar System. In Mission 4, they will learn about properties of different types of stars.

Is the bright, yellow Sun the only kind of star that might have planets orbiting it? How would planetary systems be different for other colors or types of stars? In this activity, your students will experiment to find out that a star's color is determined by its temperature. White stars are hotter than yellow stars, and red stars are the coolest. White stars burn up the fastest, yellow stars have a longer lifetime, and red stars live the longest. If two stars are the same size, the hotter one will radiate more energy than the cooler one.

Concepts

- There are many different colors, sizes, and temperatures of stars.

- The largest, hottest stars are white (and blue; still other large stars are cool and red.) Medium sized stars are cooler, and are yellow or orange. The smallest, coolest stars are red. All stars are hot.

- Star types are catalogued by the letters O B A F G K M which can be remembered by the sentence, "Oh Be A Fine Girl (or Guy) Kiss Me!" These star types span the range of star temperatures. Spectral type is determined strictly by temperature: O-type stars are the hottest stars and M-type stars are the coolest. (We study types A, G, and M today.)

- A star "burns" by converting hydrogen to helium at its center.

- The larger, hotter stars, such as O, B, and A-type stars, use up their hydrogen fuel and burn out faster. Smaller, cooler stars burn slower and live longer. A-type stars probably do not live long enough for life to evolve on any nearby planet as it has on the Earth.

Adapted from *Evolution of a Planetary System*
SETI Institute, Teacher Ideas Press, Englewood, CO, 1(800)237-6124

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Skills

- Measure with a radiometer.
- Time an experiment.
- Take averages.
- Compare models and simulations to real objects.

What You Need

PART ONE

It is ideal if a Star Center station can be set up for every group of 5-6 students. However, if your materials budget allows you to set up only a single station, arrange other projects to engage the students while groups wait their turn.

For Each Station:

- 1 Clear 200 watt light bulb
- 1 Ceramic light bulb socket
- 1 Rotary-dialed dimmer switch (that can be installed into lamp wire)
- Electrical tape
- 3 to 6 Feet of lamp wire
- 1 Electrical Plug
- 1 Wire cutters
- 1 Wire strippers
- 1 Blade screwdriver
- 1 Phillips screwdriver
- 1 Fine point permanent marker
- 1 30 cm Metric ruler or Meter stick
- 1 "New" Radiometer older radiometers lose their vacuum seal)
- 1 Stopwatch
- Optional: Clear plastic box to protect radiometer

For the Class:

- Butcher paper
- Marking pens
- Optional: "Life Story of the Earth" Image Transparencies
- Optional Overhead projector
- Optional: Calculator

For Each Student:

- Student Logbook and pencil

Adapted from *Evolution of a Planetary System*
SETI Institute, Teacher Ideas Press, Englewood, CO, 1(800)237-6124

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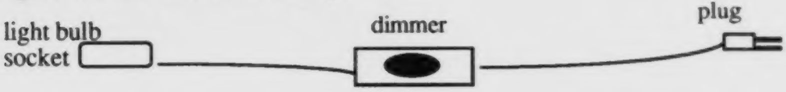
Getting Ready

PART ONE

One or More Days Before Class:

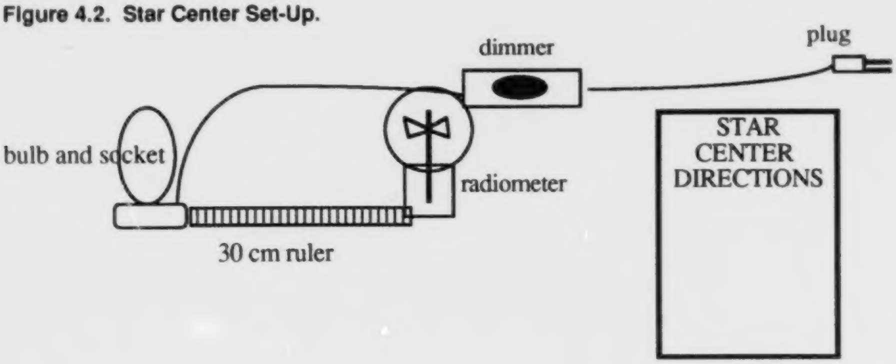
1. **Build your Star Center(s).** Refer to Figure 4.1, Star Center Assembly. First consider where you will want to locate your Star Center(s). Use enough lamp wire to span the distance from the Star Center to a wall socket easily. Attach the ceramic light bulb socket to one end of the lamp wire, following the directions on the box. Then use electrical tape to cover any exposed wire and/or metal on the bottom of the socket. Splice in the dimmer switch about a foot from the socket, using the directions on the package. Attach the plug at the end of the lamp wire. Use electrical tape to cover any exposed wire and/or metal.

Figure 4.1. Star Center Assembly.



2. **Calibrate your dimmer switch.** Screw your clear 200 watt bulb into the socket, and plug in the Star Center. Set out the 30 cm ruler and place your radiometer at the end of it as shown in Fig. 4.2, Star Center Set-Up (or mark 30 cm on a meter stick, and place the radiometer at 30 cm away from the bulb).

Figure 4.2. Star Center Set-Up.



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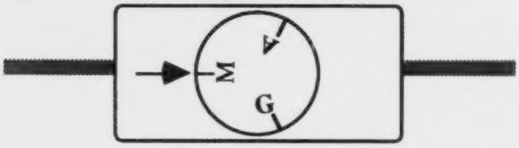
Use the permanent marker to draw an arrow on the body of the dimmer, as shown in Figure 4.3, Calibrating the Dimmer Switch. The arrow will show the students where to set the dial for each of their measurements (A, G, and M).

Figure 4.3. Calibrating the Dimmer Switch.



Calibration for the A type Star: Turn the switch up to its highest setting. Mark the dial with a small line that lines up with the arrow, and write "A" by the mark.

Calibration for the M type Star: While watching the bulb, slowly spin the dimmer down to a point where the filament glows orange/red. When it is at a very low setting it will flicker. Turn it up until the flicker is less noticeable. Test your radiometer to see if it's vanes turn at this setting. If not, turn the dimmer up until the radiometer does turn, or replace your radiometer (it may be too old). Make a mark for the M star at the lowest setting that will turn the radiometer's vanes.

Calibration for the G type Star: Turn the dimmer all the way up to its highest point again, and then turn it down until the bulb glows yellow. This should be about midway between your A and M marks. Make a mark for the G star.

Teacher's Note: *Starting from the lowest setting and turning towards the highest, gives very different readings. Encourage your students to use a consistent method to collect this data, i.e., starting from highest to lowest.*

4. **Optional:** Radiometers are made from very thin glass, and therefore are breakable. Some teachers have found it useful to glue their radiometer into a small clear plastic box.

Just Before the Lesson:

1. Set up one or more Star Centers as shown in Fig. 4.2, Star Center Set-Up. Put the Star Centers in places that do **not** have another source of heat, such as a sunny window, an incandescent light, or a heater.

2. Before each use of a completed Star Center, try your radiometer(s) with each dimmer setting to be sure it will

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still turn at the 30 cm distance. If you have an older radiometer, it may tend to turn more slowly because air has leaked in.

If necessary, you can shorten the distance at which students make their measurements, as long as the measurements for all bulbs are made at the same distance.

3. Draw a chart like Table 4.1 on the butcher paper or blackboard for students to record their data. Hang the chart at the front of the room.

Table 4.1. Radiometer Turns in 10 Seconds.

Star Types	A (White)	G (Yellow)	M (Red)
Group 1			
Group 2			
Group 3			
Group 4			
Group 5			
Average			

Classroom Action

PART ONE

1. **Review**. Remind the students that in the last Mission, they learned how planets may form around a star. But are all stars the same? Now we will study how stars can vary in their color and temperature. Star types were first invented to identify stars with different colors. For example, our Sun is a G type star. What color is it? *Yellow.*

Star types are catalogued by the letters O B A F G K M which can be remembered by the sentence, "Oh Be A Fine Girl (or Guy), Kiss Me!" These star types span the range of star temperatures. Spectral type is determined strictly by temperature: O-type stars are the hottest stars and N-type stars are the coolest. We will study three types of stars: white (A), yellow (G), and red (M).

2. **Mission Briefing**. Have the students refer to the Mission Briefing in their Student Logbook, as one student reads it aloud.

> "In order to decide which types of stars to search first for planets that could have life, we would like you to conduct some experiments to determine some of the ways that stars differ."

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3. **"What Do You Think?" Activity/Discussion**. Let the students write their opinions on the pre-activity questions ("What Do You Think?"). Then invite them to share their answers with the class in a discussion.

4. **Demonstration**. Show the students the Star Center you set up at the front of the classroom. Explain that a single bulb can represent three different star types by using a dimmer switch at three different settings. The three bulb settings represent stars that are white (A), yellow (G), and red (M).

Tell students that the light bulb they see in the Star Center represents a star—a burning ball of gases very far away. We are going to observe how the color changes as the temperature of the bulb is changed.

Turn the lights off in the classroom and turn the bulb on to its highest, brightest setting. Ask the students what color the bulb is. *White*. Begin dimming. The color will become noticeably more yellow. Continue slowly dimming the bulb, stopping each time there is a change in color, to ask students what color they see. At the end, ask the students: "What colors did you see?" *White, yellow, red and colors in-between*. Point out that white, yellow and red are three types of stars: A, G and M respectively.

Their Student Logbook has a chart that gives facts about each of the basic types of stars. You may want to refer to this chart.

Tell the students that their job is to measure the heat (infrared radiation) produced by the model A, G and M type stars. A radiometer is used to measure heat (infrared radiation). The faster the radiometer spins, the more heat (infrared radiation) is being radiated by the bulb. (For an explanation of how a radiometer works, see the Appendix.)

Go over the directions in the Student Logbook, demonstrating each step. Emphasize that they cannot begin counting until the radiometer reaches full speed, which takes about thirty seconds. It is **important** not to bump the radiometer, since it is very fragile. In order to stop the radiometer vanes between measurements, tilt the radiometer slightly for a few seconds and then gently let it down again.

Mention **safety** considerations:

- No more than one group at the Star Center at one time.
- Do not touch the bulbs.
- Handle the radiometers very carefully.
- Do not remove the radiometers from the Star Center.

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5. **Activity**. Give the students time to complete their observations and data-taking. Provide other activities for early finishers. When groups finish, they should record their data on the class data chart that you have drawn on the butcher paper or on the black board.

Closure

1. **Data**. Have a student or teams of students use a calculator to average the results from the various groups. Ask the students for the conclusions that they can draw from this experiment. Go over the questions on the data sheet. The students will find that the A-type star is hottest (gives off the most infrared radiation) and the M-type star is coolest (gives off the least infrared radiation).

2. **Lecture**. You may also wish to emphasize that all stars are really hot. Even the coolest M star, at 3,300 °C is at least 13 times hotter than the hottest kitchen ovens can get. Also, the temperatures listed are **surface** temperatures of stars. Temperatures at the center or **cores** of stars are much hotter.

3. **Discussion**. Ask the students look at Question 3 in the **"What Do You Think Now"** section of their Student Logbook. Invite discussion. Some students may realize that if our Sun were an A-type star and the Earth were the same distance from it, it would be too hot to live on Earth. Others may point out that the Earth could orbit at a comfortable distance from an A-type star, much further than its current position, but that sunlight would be white, not yellow.

4. **Optional Transparencies.** Using transparencies, quickly review the Video Image show with emphasis on the Timeline will provide the students with the information that it took over three **billion** years for complex life to appear on Earth. Use information about the lifetimes of stars of different types from Table 4.3, "Types of Stars Information Table". Direct the students' attention to the Timeline that they created during their last Mission. Ask the students: "How long did it take for complex life to evolve on the Earth?" *Over three billion years!* Have the students notice the "lifetime" column in table 4.3, and then ask them what would happen if the Earth orbited an A-type star. *Complex life would probably have never evolved on Earth, as an A -type star would "burn out" long before complex life could get started.* Since an A-type star only lives 100 **million** years complex life could never have evolved on our planet!

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5. **"What Do You Think Now?"** Have students answer the post activity questions on the Logbook sheet ("What Do You Think Now?") After students have completed their answers, invite students to share their responses.

6. **Preview**. Tell the students that in the next Mission, we will finding out how a life-bearing planet orbiting other star types, such as A-type and M-type stars, could still be at a comfortable temperature. (Keep the completed "Radiometer Turns in 10 Seconds" Table 4.1 for the next Mission.)

Going Further

DEMONSTRATION: LIFETIMES OF STARS

Set up three Star Centers where they can be seen clearly from all over the room and where it won't be bumped or handled by students. Announce that you are going to demonstrate the comparative lifetimes of the three stars. Turn on the dimmer setting on the first to A-type star, the second to G, the third to M and set a timer for 5 minutes. Explain that the time scale you are using is 5 minutes = 100 million years (0.1 billion years). At this scale the White A-type star would live for 5 minutes. A Yellow G-type star for 8 hours. And a Red M-type star for almost a week (80 hours). Mark your calendar or have a student in charge of turning off the 'stars' at the appropriate times. (If you have only one star center, do the lifetimes in series.)

ACTIVITY: MORE RADIOMETER STUFF!

Have the students use the radiometer to measure infrared radiation from various things: our sun, other lights, fluorescent lights, heaters, and so forth. What conclusions can they draw?

ACTIVITY: COLORFUL STARS AT NIGHT

Do some observations of the night sky; try to find stars that are red, white, yellow, or blue and classify them by star type. Use a star chart to get the star's name and look it up in a stellar atlas.

ACTIVITY: ASTROPHOTOGRAPHY

Take a long exposure (2 seconds) of a familiar constellation from a very dark area. If you move the camera while you take the picture you can streak the stars which will show you what colors they are. From your developed picture determine what types of stars you were looking at.

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Name________________________________ Date____________

Mission 4

Investigating Types of Stars

Dr. Laurance Doyle

Stellar Astronomer on the SETI Academy Team.

Mission Briefing. "In order to decide which types of stars to search first for planets that could have life, we would like you to conduct some experiments to determine some of the ways that stars differ."

What do you think?

1. From Earth, stars appear to be different colors: blue, white, yellow, orange, and red. What might cause one star to be a different color than another star?

2. What other ways might stars be different?

3. The Earth orbits a yellow star. What things would be different on Earth and in our Solar System if our star was red?

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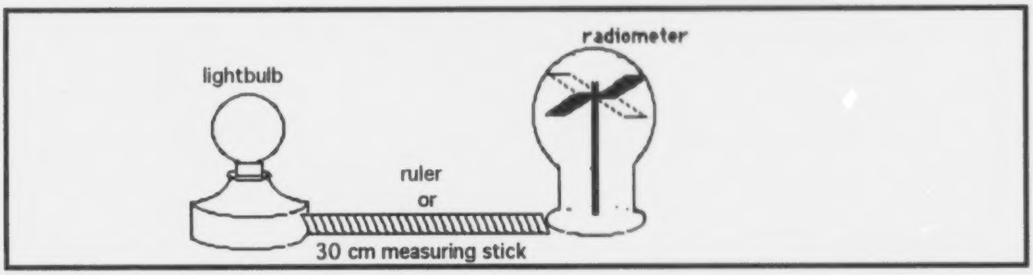
Mission 4: Investigating Types of Stars

Star Center Instruction Sheet

1. Turn the dimmer switch all the way off. Place one end of the ruler or measuring stick at the base of the socket. Place the radiometer at the other end.



2. Stop the radiometer's vanes. Turn the dimmer switch to the **A** star mark. Wait 30 seconds. Looking from the top follow one blade around with your finger. Have your partner time 10 seconds, saying "Start" and "Stop." Count how many times the vanes go around during the ten seconds. Record the number of turns in 10 seconds below:

A Star:	_______ turns in 10 seconds	Color______________
G Star:	_______ turns in 10 seconds	Color______________
M Star:	_______ turns in 10 seconds	Color______________

3. Turn the dimmer knob down to the **G** star mark. Stop the radiometer's vanes. Set it back down at the end of the ruler. Wait 30 seconds. Time, count and record the turns of the radiometer vanes just like you did for the A star.

4. Now take the same measurements for the **M** star. Don't forget to stop the radiometer fully, then wait 30 seconds for it to reach full speed. Record your data. Add all your data to the class chart.

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Mission 4

Investigating Types of Stars

What do you think, now?

After completing your investigation, please answer these questions:

1. From Earth, stars appear to be different colors: blue, white, yellow, orange, and red. What causes one star to be a different color than another star?

2. What other ways are stars different?

3. The Earth orbits a yellow star. What things would be different on Earth and in our Solar System if our star was white? (Consider what you learned from the Video Image show about how long it was before complex life appeared on Earth.)

Type	Color	Temperature	Lifetime
O	blue	35,000°C	10 million years
B	blue-white	21,000°C	40 million years
A	white	10,000 °C	100 million years
F	yellow-white	7,500°C	5 **billion** years
G	yellow	6,000 °C	10 **billion** years
K	orange	4,700 °C	50 **billion** years
M	red	3,300 °C	100 **billion** years

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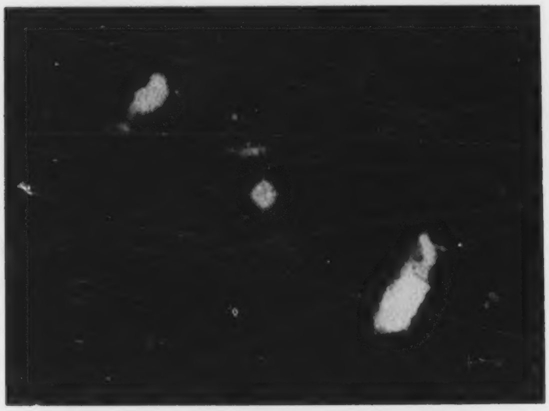


RESOURCES FOR EXPLORING THE LIFE STORY OF THE STARS

by Andrew Fraknoi
Astronomical Society of the Pacific
390 Ashton Avenue
San Francisco, CA 94112

NOTE: This resource list concerns itself with the birth, life and death of stars. There are separate bibliographies in the Notebook on finding stars in the sky and star mythology.

Books and articles marked with a • are especially useful for those just becoming familiar with the subject.

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

Books on the Life Story of Stars in General:

Cohen, M. *In Darkness Born: The Story of Star Formation.* 1988, Cambridge U. Press. An astronomer chronicles how we learn about the beginnings of a star's life.

- Cooke, D. *The Life and Death of Stars.* 1985, Crown. A clear introductory survey by a journalist.

- Kaler, J. *Stars.* 1992, Scientific American Library & W. H. Freeman. An outstanding introduction by an astronomer.

Kippenhahn, R. *100 Billion Suns: The Birth, Life, and Death of Stars.* 1983, Basic Books. Good introduction by a European astronomer.

Moore, P. *Astronomers' Stars.* 1987, Norton. Introduces the lives of stars by profiling 15 specific stars that have been important in the development of astronomical ideas.

Articles on the Life Story of Stars in General:

Bennett, G. "The Cosmic Origins of the Elements" in *Astronomy,* Aug. 1988, p. 18. On role stars play in making elements.

- Croswell, K. "Visit the Nearest Stars" in *Astronomy,* Jan. 1987, p. 16.

Darling, D. "Breezes, Bangs, and Blowouts: Stellar Evolution Through Mass Loss" in *Astronomy,* Sep. 1985, p. 78; Nov. 1985, p. 94.

Fortier, E. "Touring the Stellar Cycle" in *Astronomy,* Mar. 1987, p. 49. Observing objects in the sky that show the different stages in the lives of stars.

Kaler, J. "Journeys on the H-R Diagram" in *Sky & Telescope,* May 1988, p. 483. On the diagram used to help understand and trace the life story of stars.

Kaler, J. "Giants in the Sky: The Fate of the Sun" in *Mercury,* Mar/Apr. 1993, p. 34. On the later evolution of stars like the Sun.

- Lada, C. "Deciphering the Mysteries of Stellar Origins" in *Sky & Telescope,* May 1993, p. 18. A fine review of current ideas.

Stahler, S. & Comins, N. "The Difficult Births of Sunlike Stars" in *Astronomy,* Sep. 1988, p. 22.

Books on the Death of Stars:

- Greenstein, G. *Frozen Star: Of Pulsars, Black Holes, and the Fate of Stars.* 1984, Freundlich. Eloquent discussion of the ways stars can die and how we learn about them.

- Kaufmann, W. *Black Holes and Warped Spacetime.* 1979, W. H. Freeman. Clearly written primer for beginners.

- Marshall, L. *The Supernova Story*, 2nd ed. 1994, Princeton U. Press. Very nicely written introduction to exploding stars.

Thorne, K. *Black Holes and Time Warps.* 1994, W. W. Norton. Definitive introduction to these intriguing objects, by a noted scientist.

Articles on the Death of Stars:

Filippenko, A. "A Supernova with an Identity Crisis" in *Sky & Telescope*, Dec. 1993, p. 30. Good review of current research.

Helfand, D. "Pulsars" in *Mercury*, May/June 1977, p. 2.

Hewish, A. "Pulsars After 20 Years" in *Mercury*, Jan/Feb. 1989, p. 12. Review by one of the discoverers.

- Kaler, J. "The Smallest Stars in the Universe" in *Astronomy*, Nov. 1991, p. 50. On white dwarfs and neutron stars.
- Kirshner, R. "Supernova: The Death of a Star" in *National Geographic*, May 1988, p. 618. Superb review of Supernova 1987A.

Kirshner, R. "The Earth's Elements" in *Scientific American*, Oct. 1994, p. 59. Where the atoms in our bodies come from and how it is connected to the deaths of stars.

- Overbye, D. "God's Turnstile" in *Mercury*, Jul/Aug. 1991, p. 98. Introducing the black hole.

Parker, B. "Those Amazing White Dwarfs" in *Astronomy*, July 1984, p. 15.

Parker, B. "In and Around Black Holes" in *Astronomy*, Oct. 1986, p. 6.

SELECTED READINGS FOR STUDENTS

Grades 4-6:

Apfel, N. *Nebulae: The Birth and Death of Stars.* 1988, Lothrop, Lee & Shephard.

Asimov, I. *The Birth and Death of Stars.* 1989, Gareth Stevens.

Asimov, I. & Reddy, F. *Mysteries of Deep Space: Black Holes, Pulsars, Quasars.* 1994, Gareth Stevens.

Couper, H. & Henbest, N. *The Stars.* 1987, Franklin Watts.

Simon, S. *Stars.* 1986, Mulberry/William Morrow.

Grades 7-9:

Asimov, I. *How Did We Find Out About Black Holes?* 1978, Walker & Co.

Branley, F. *Superstar: The Supernova of 1987.* 1990, Crowell.

Gallant, R. *Fires in the Sky: The Birth and Death of Stars.* 1978, Four Winds Press.

Lampton, C. *Supernova!* 1988, Franklin Watts.

Ridpath, I. *The Stars.* 1988, SchoolHouse Press.

SELECTED AUDIOVISUAL MATERIALS

Black Holes and Warped Spacetime (45-min video from the Astronomical Society of the Pacific) A taped public lecture by the late William Kaufmann.

A Brief History of Time CD-ROM (1994, W.H. Freeman) CD-ROM version of Stephen Hawking's best-selling book. (By the way, the documentary film with the same name is a profile of Hawking, but, shamefully, contains almost no science explanations.)

Death of a Star (60-min video, 1988, episode of the NOVA TV series, from PBS Video and the Astronomical Society of the Pacific) Good television show on Supernova 1987A.

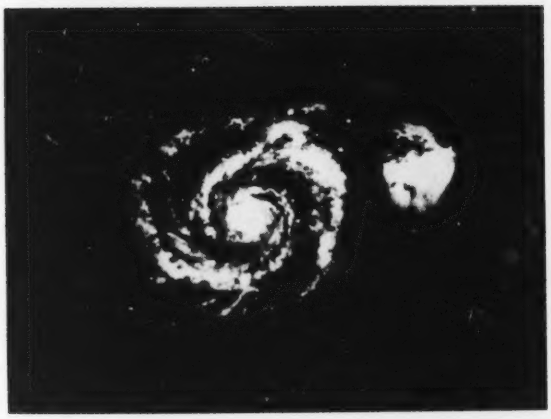
The Evolution of the Stars (2 slide sets from Science Graphics) Two sets of illustrations showing the stages in the lives of low mass and high mass stars.

"The Lives of the Stars" (1979, 60-min video, episode of the Cosmos public television series, from Turner Home Video or the Astronomical Society of the Pacific)

"Stardust" (1991, 60-min video, part of The Astronomers public television series, from PBS Video) Focuses on astronomers who work on the birth and death of stars.

H

GALAXIES AND THE UNIVERSE



ACTIVITIES INCLUDED IN GALAXIES AND THE UNIVERSE

ACTIVITY	ESTIMATED GRADE LEVEL											
Grades	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
H-1. Your Galactic Address Students identify their location on a series of maps, at successively larger scales, from their classroom to the Milky Way Galaxy.				▨	▨	■	■	■	■	▨	▨	▨
H-2. Cosmic Calendar and Time-Line Scale Model of the Age of the Earth Students create time-lines of major events in the history of the universe, and in the age of the Earth.				▨	▨	■	■	■	■	▨	▨	▨
H-3. How Many Stars? Students count grains of sand to develop a sense of the 200 billion stars in our galaxy.							■	■	■	▨	▨	▨
H-4. A Ballooning Universe Students use an inflating balloon to model the expanding universe and to measure the increasing distance between points representing galaxies.								■	■	▨	▨	▨
H-5. The Expanding Universe Students investigate wave behavior and the Doppler Shift, and they plot recession speeds of galaxies to illustrate Hubble's Law.								■	■	▨	▨	▨
H-6. Visualizing the Expansion of Space Students use special overhead transparencies to create a simulation of the expansion of the universe.								■	■	▨	▨	▨

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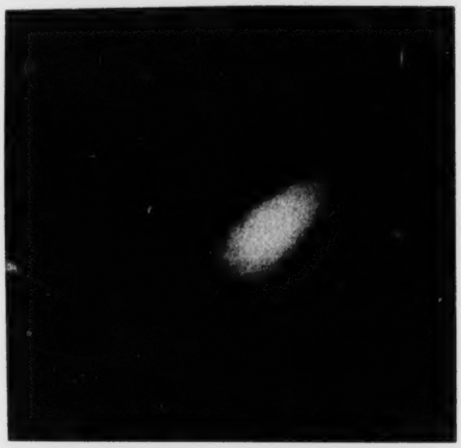
■ - Grade levels recommended by authors ▨ - Can be extended to these grade levels

About the Activities:
Galaxies and the Universe



KEY IDEAS IN "GALAXIES AND THE UNIVERSE"

- It is only in the past few decades that astronomers have devel oped the modern theory of the universe, including its organization into galaxies, its current expansion, and its origin some 10-20 billion years ago.
- In order for our students to be scientifically literate, they will need a framework to which they can relate the new discoveries.
- The *Benchmarks for Science Literacy* recommends the 6-8 grade level as the time to begin teaching some of these ideas, but to recognize the conceptual difficulties involved.
- By the end of eighth grade it is realistic to expect students to understand that the Sun is a medium-sized star located near the edge of a disk-shaped galaxy.
- High school is the time when students are able to grasp the character of the cosmos, including concepts from physics and chemistry, insights from history, mathematical ways of thinking, and ideas about the role of technology in exploring the universe.

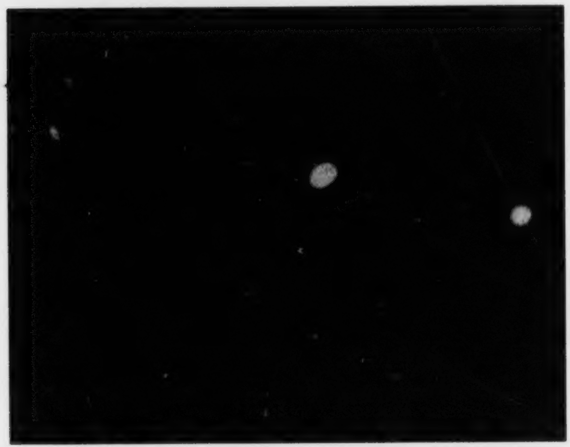
It is only in the twentieth century that astronomers have become aware that our sun is just one of about 400 billion stars in a huge pinwheel of stars called the Milky Way Galaxy and that there are billions of such galaxies in the known universe. Within the past three decades, astronomers have found very strong evidence that the universe is not static and everlasting, but that it is expanding and evolving, and that it had an origin some ten to twenty billion years ago. In fact, these theories are so new that every few days articles appear in the newspapers about significant new discoveries.

If we want our students to be scientifically literate, it is important that they not only understand what they see in the sky, but that they are able to understand new discoveries that will be made during their lifetimes. To do this, they will need a framework to which they can relate the new discoveries, which will itself be modified with each new scientific advance.

The *Benchmarks for Science Literacy* recommends the 6-8 grade level as the time to begin teaching some of these ideas, but to recognize some of the conceptual difficulties involved. "Using light-years to express astronomical distances is not as straightforward as it seems. (Many adults think of light-years as a measure of time. See "Background: Scale of the Solar System" for a more in depth discussion about light-years and cosmic distances.) Beginning with analogs such as 'automobile-hours' may help." (*Benchmarks*, page 63.) But by the end of eighth grade it is realistic to expect students to understand that "The Sun is a medium-sized star located near the edge of a disk-shaped galaxy of stars, part of which can be seen as a glowing band of light that spans the sky on a very clear night. The universe contains many billions of galaxies, and each galaxy contains many billions of stars. To the naked eye, even the closest of these galaxies is no more than a dim, fuzzy spot." (*Benchmarks*, page 64.)

According to the *Benchmarks*, high school "is the time for all the pieces to come together. Concepts from physics and chemistry, insights from history, mathematical ways of thinking, and ideas about the role of technology in exploring the universe all contribute to a grasp of the character of the cosmos. In particular, the role of gravity in forming and maintaining planets, stars, and the solar system should become clear. The scale of billions will make better sense, and the speed of light can be used to express relative distances conveniently. By the end of 12th grade, students should know that...on the basis of scientific evidence, the universe is estimated to be over ten billion years old. The current theory is that its entire contents expanded explosively from a hot, dense, chaotic mass." (*Benchmarks*, page 65.)

The first few activities in this section help students place themselves in space and time, using familiar concepts as ways to grasp the vast stretches of space, time, and the huge numbers of stars. The last three activities help students to understand the current theory of an expanding universe.



Cluster of Galaxies

BACKGROUND:
GALAXIES AND THE UNIVERSE

Our Sun is one of more than a hundred billion stars that make up the Milky Way Galaxy. Every individual star you can see with your naked eye at night is also part of our Galaxy. If you go outside on a warm summer night far from city lights, you'll see a faint band of light stretching across the sky. The ancient Romans called this band the "Milky Way." It is actually the glow of billions of stars in the disk of our Galaxy, so distant and yet so numerous that their light merges together into a faint band.

From a great distance, our Galaxy would look something like a Frisbee with a softball in the middle. The stars are arranged in an immense disk, more than 100,000 light years across [see "The Scale of the Solar System" section for the definition of a light year]. The disk is very thin, not much more than 3000 light years thick. At the Galaxy's center, the stars have a more spherical distribution, bulging far out above and below the disk. If you look at the constellation of Sagittarius, you're looking toward the center of our Galaxy. Our Sun sits inside the disk, a little over half of the way out (27,000 light years) from the Galactic center. This is why the "Milky Way" looks like a band in the night sky.

The Milky Way Galaxy is our galactic home—our island of stars. But just as there are many islands in an ocean, there are many other galaxies—billions and billions of them, in fact. In some, including the Milky Way, the stars are arranged in beautiful spiral patterns. These giant cosmic pinwheels slowly rotate; it takes our Sun about 200 million years to complete one revolution around the galaxy! The nearest large galaxy to the Milky Way is a spiral galaxy called M31, a nearly identical twin to the Milky Way located about two million light years away. You can just barely see M31 without a telescope or binoculars, if you are far from city lights. It looks like a faint fuzzy patch in the constellation of Andromeda, and is best seen during summer nights. It's the farthest thing you can see with the naked eye. Other galaxies have a more amorphous shape. Elliptical galaxies do not have distinctive disks; their stars are arranged into large oval shapes. Galaxies that do not fit these two simple patterns are called irregular galaxies; they often show disorganized or distorted shapes or are too loosely distributed to have much of a shape at all. Astronomers aren't sure why galaxies have such different shapes.

Apparently, galaxies don't like to be alone. Most are found in small groupings or large clusters. The Milky Way and M31 are the main members of a small family of galaxies known as the Local Group. Most of the three dozen or so members of the Local Groups are very small elliptical galaxies, irregularly distributed throughout a volume of space almost four million light years across. Most of the smaller galaxies in our group cluster near either the Milky Way or M31. Some astronomers have likened the two large spiral galaxies to sharks swimming through an ocean, the tiny galaxies swarming around them reminiscent of remora fish swimming alongside the sharks. But our group is only a small one in the ocean of space; larger clusters can contain hundreds and even thousands of galaxies.

Within the past few decades, astronomers have come to realize that galaxies within these groups and clusters sometimes collide with one another and merge. The average separation between galaxies in a larger cluster is only about 20 times their diameter, and so, like elephants moving about under a circus tent, they will occasionally bump into each other. Within a galaxy, however, the stars are so far apart (the average separation between stars is about ten million times their diameter) that even a head-on collision with another galaxy rarely results in collisions between stars. In some collisions, especially those between two galaxies of widely disparate size, all the stars in the smaller galaxy can actually be "absorbed" and become part of the larger galaxy; this process is known as "galactic cannibalism." Our own Milky Way Galaxy is in the process of (slowly) "eating" the Large Magellanic Cloud, one of two tiny satellite galaxies visible to viewers in the Southern Hemisphere. Eventually, the Large Magellanic Cloud will cease to exist, its stars added to those of the Milky Way.

As you go farther and farther out in space, you see larger and larger groupings of galaxies. Small galaxy associations, like the Local Group, cluster with other groups, forming superclusters of galaxies. The Local Supercluster (of which the Local Group is one member) stretches across some 150 to 250 million light years. These superclusters are linked into even larger structures that are variously called filaments, pancakes or walls, which surround enormous regions of space devoid of any galaxies. This large-scale structure of superclusters has been likened to a foam of soap suds, as galaxies cluster on the surfaces of the bubbles, with nothing inside them.

Astronomers have found it difficult to explain how this large-scale structure came to be. The study of how the universe began, how it got to its present state, and what will happen to it in the future (called "cosmology") is among the most speculative areas of astronomy. Still, astronomers do agree on two things: that the universe had a definite beginning, the so-called Big Bang, and that it has been expanding outward ever since. According to the Big Bang theory, the universe suddenly began expanding from an incredibly dense, incredibly hot initial state about 10-20 billion years ago. The term "Big Bang" is a bit of a misnomer, since it makes us think of a tremendous explosion in space, like those that fill action movies. In reality, it was more of a sudden, rapid expansion of space itself. The universe isn't expanding into anything; the universe itself (space with matter and energy in it) is expanding.

In 1964, two physicists at Bell Laboratories in New Jersey, Arno Penzias and Robert Wilson, were experimenting with a special low-noise radio antenna. They picked up an annoying extra signal that didn't change no matter what direction the antenna pointed or the time of day or the season. They thought the "noise" was due to pigeons living in their antenna, but, despite shooing away the pigeons and cleaning up their droppings, the noise persisted. Later they realized that what they thought was noise was really the faint, leftover echo of radiation from the time of the Big Bang coming to us from all over the universe. It was the first observational evidence in support of the Big Bang theory, and earned Penzias and Wilson the 1978 Nobel Prize for physics.

No matter what direction we look, all distant galaxies appear to be moving away from us. This provides visual confirmation of the universe's expansion. Think of individual galaxies as raisins in a loaf of raisin bread. As the dough rises, all the raisins move away from one another; raisins that were initially relatively far apart seem to move away faster than those that were originally close together. In the same way, the more distant a galaxy, the faster it seems to be moving away from us. That doesn't mean we're in the center of the universe. All the raisins move away from all the other raisins, regardless of their position in the loaf. In ancient times, people thought the Earth was the center of the universe. We now know that the Earth orbits a nondescript star located in the outer regions of an ordinary galaxy that's just one of billions of galaxies in the universe. There seems to be nothing special about our location in the cosmos. If anything can make us special, it is how much we have managed to learn about the universe in which we live.

YOUR GALACTIC ADDRESS

ACTIVITY H-1

GRADE LEVEL: 6-9

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What's This Activity About?

Many different scaling activities exist for the solar system, but few include scales up to that of a galaxy. This simple activity will help students put cosmic structures and distances into perspective. The activity also helps to reinforce the idea that planets make up solar systems, which are extremely small when compared with a galaxy.

What Will Students Do?

Students identify and label their location on a series of scaled maps, at successively larger scales, from their classroom to the Milky Way Galaxy.

Tips and Suggestions

- This exercise builds on the concepts illustrated in the video *Powers of Ten* (available from the catalog of the Astronomical Society of the Pacific).
- For earlier grades, consider using the story *My Place in Space* by Robin and Sally Hirst (1988 Orchard Books/Franklin Watts), to complement the activity.
- For later grades, include additional mathematics by asking students to determine an appropriate scale for each map. Have students research the real sizes of the objects shown on each map. Then students should measure the pictures and calculate the scale factors.

  For example: *Address Map 7 shows an image of the Earth. The original image before we reduced it for this notebook was about 10 cm wide. The Earth's diameter is 12,760 km. So, the scale factor for that map would be 1 cm = 1,276 km. (Your students will need to make new measurements for each of the pictures.)*

What Will Students Learn?

Concepts

Relative sizes of human structures compared with planets, the solar system and the galaxy

Inquiry Skills

Ordering
Communicating

Big Ideas

Scale

Your Galactic Address

Usually you think of your address as only three or four lines long: your name, street, city, and state. But to address a letter top a friend in a distant galaxy, you have to specify where you are in a greater span of scales.

Materials

☐ For each student, one of each of the address maps: (1) Classroom, (2) School, (3) Neighborhood, (4) City, (5) State, (6) Country, (7) World, (8) Solar System, (9) Milky Way Galaxy

Before Class

1. Get a map of your school and reduce/photocopy it (or sketch a map of your school) so that it fits on Galactic Address Map 2 (page 29) as a photocopy master. (Another option would be to make this an additional exercise for your students.)
2. Reduce/photocopy a map of your neighborhood and a map of you city to make a photocopy master for Galactic Address Maps 3–4 (page 30).
3. Reduce/photocopy a map of your state to put in the upper section of Galactic Address Map 5 photocopy master (page 31).
4. Use the resulting photocopy masters (pp. 29–32) to make a complete set of Galactic Address Maps for each student or team of students.

In Class

1. Ask a student volunteer for his or her address.
2. Explain if you were to write a letter to an alien being from another planet, you would need a much more detailed address than that! A complete galactic address must span many distance scales.
3. Hand out Galactic Address Maps 1 and 2. Have the students make a rough sketch map of the classroom with the desks numbered. Have each student invent a symbol to represent themselves and mark that symbol on the appropriate spot on their sketch. Have them write their desk number in the space provided.
3. Have the students mark their symbol on the proper room number in the map of the school Galactic Address Map 2. Have them mark their room number in the blank provided.
4. Hand out Galactic Address Maps 3 and 4. Have students mark their symbols in the proper places on each map, neighborhood and city. Have them fill in the address blanks, "street number," and "street" on the right side of the page. They can all use the same school address.
5. Hand out Galactic Address Maps 5 and 6. Have students mark their symbols on each map appropriately. Have them write the proper "City" and "State" in the spaces on the right side of the page.
6. Hand out Galactic Address Maps 7 and 8. Have students mark their symbols on each map and write the correct "Country" and "Planet" in the spaces on the right side of the page.
7. Hand out Galactic Address Map 9. Tell the class that our solar system is about 2/3 of the way from the center to the edge of the galaxy. Also, we are located on the outer edge of the "major spiral arm." The students can use those clues to mark their symbols at their location in the Milky Way Galaxy. Have them fill in the "Galactic Arm" space on the right side of the page.
8. Finally, ask the students to write in the bottom part of Map 9 their complete galactic address, all the way from which desk they are sitting in to which galaxy we are in. Tell them that the Milky Way is part of a cluster of galaxies called *The Local Group*.

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Galactic Address Map 1: Classroom

Please mark where your desk is.

I am at desk number ____________

Galactic Address Map 2: The School

Please mark where your classroom is.

I am in classroom ____________

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Galactic Address Map 3: The Neighborhood

Please mark where your school is.

Galactic Address Map 4: The City

Please mark where your school is.

Street Number and Street: ____________

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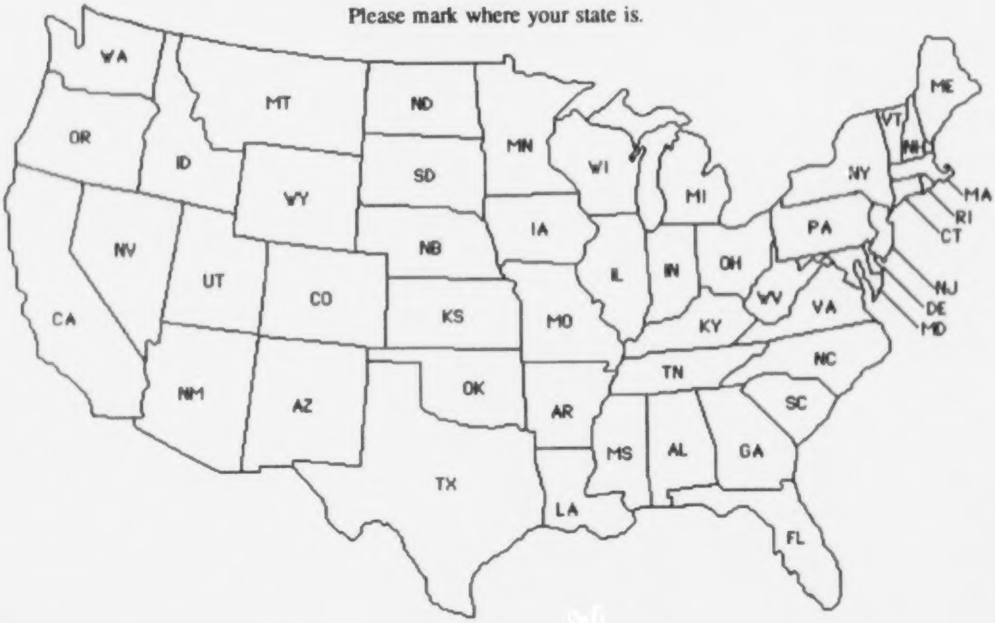
Galactic Address Map 5: The State

Please mark where your city is.

My City ____________

Galactic Address Map 6: The Country

Please mark where your state is.


WA
MT
ND
MN
ME
OR
ID
SD
WI
VT
NH
NY
MI
MA
WY
IA
RI
NV
NB
PA
CT
IL
IN
OH
UT
CO
NJ
WV
VA
CA
KS
MO
KY
DE
MD
NC
TN
OK
NM
AZ
AR
SC
MS
AL
GA
TX
LA
FL

My State: ____________

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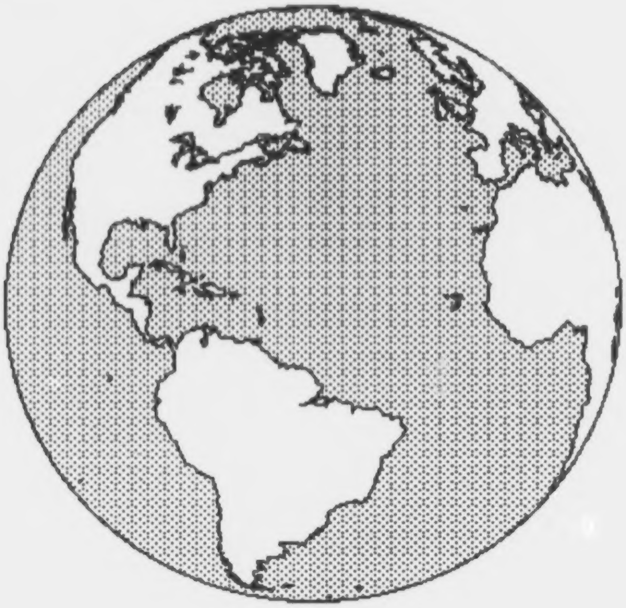
Galactic Address Map 7: The World

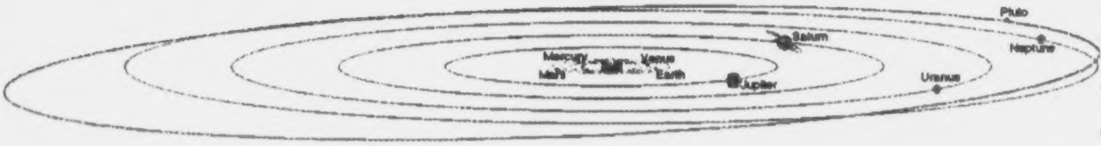
Please mark where you are.



My Country: ____________

Galactic Address Map 8: The Solar System

Please mark where your world is.


Pluto
Saturn
Neptune
Mercury
Venus
Mars
Earth
Jupiter
Uranus

My planet: ____________

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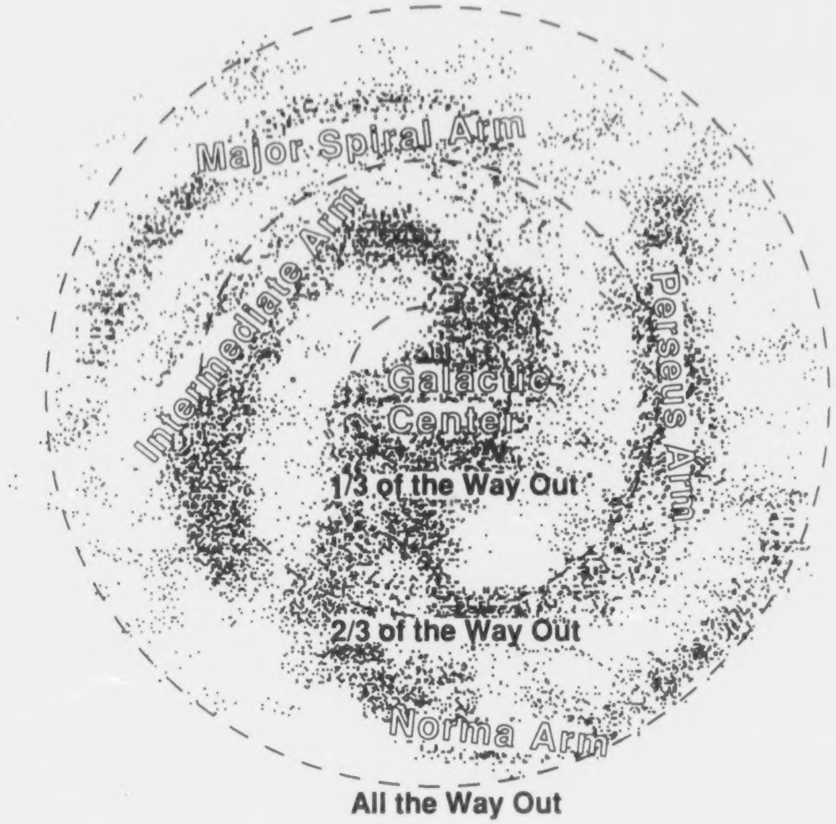
Galactic Address Map 9: The Milky Way Galaxy

Please mark where your world is.


Major Spiral Arm
Intermediate Arm
Perseus Arm
Galactic Center
1/3 of the Way Out
2/3 of the Way Out
Norma Arm
All the Way Out

My Planet System: ____________

Please write your complete galactic address below.

Your Name:

1. Classroom:
2. School:
3. Street & #:
4. City:
5. State:
6. Country:
7. Planet:
8. Planet System:
9. GalacticArm:
10. Galaxy:
11. Galaxy Cluster:

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COSMIC CALENDAR & TIMELINE/SCALE MODEL OF THE AGE OF THE EARTH

ACTIVITY H-2

GRADE LEVEL: 6-9

Source: "Cosmic Calendar" activity by Therese Puyau Blanchard, Arun Elementary School. Adapted by the staff of Project ASTRO, Astronomical Society of the Pacific. The Cosmic Calendar is adapted with permission from Carl Sagan's *The Dragons of Eden* (Copyright © 1977 by Carl Sagan) and from his television series *Cosmos*.

"Timeline/Scale Model of the Age of the Earth" by Peter H. Burkey, Fennville High School, adapted from Payne, Falls, and Whidden, *Physical Science: Principles and Applications*, 5th edition, Wm. C. Brown Publisher, 1989.

What's This Activity About?

Cosmology—the study of our universe, how it began, and how it has evolved—can be stimulating for students. But many are overwhelmed by the vast eons of time between today and the beginning of the universe. Because the numbers are so large, some students feel that scientists cannot possibly understand what was going on so long ago. It is important to show students that we can develop useful scientific theories of the early universe and its evolution. To help them with the process, we can provide a "bridge" across time that will make the numbers more meaningful. We can help students begin to appreciate their place in a cosmic time line, and these two activities are designed to do just that.

In "Cosmic Calendar," students scale the evolution of the universe to a one-year calendar, with the Big Bang occurring on the first moment of January 1st. In "Timeline/Scale Model of the Age of the Earth" students create a timeline for the evolution of our planet's surface, atmosphere, and life on a 10-meter strip of adding-machine tape.

What Will Students Do?

Cosmic Calendar:

Working in groups, students estimate where on a one-year timeline a list of significant events should be placed. The order and general placement of the events on the annual timeline is discussed and refined as a class. More advanced students can research the dates of significant events and calculate when in the model timeline these events occurred.

Timeline/Scale Model of the Age of the Earth:

Using a long piece of adding-machine tape, students first determine a timeline scale based on the approximate age of the Earth and the length of the tape. The activity explains the mathematics required to determine the scale. Then using the supplied list of events, students measure and mark off event locations on the tape.

continued

What Will Students Learn?

Concepts
- Cosmology
- The Big Bang
- Major events in the history of the universe and the Earth
- The age of the Earth
- Geological and biological evolution

Inquiry Skills
- Ordering
- Organizing
- Calculating
- Visualizing
- Graphing

Big Ideas
- Evolution
- Scale

Tips and Suggestions

- For earlier grades, give students the selected set of events, or have them create pictures for the events provided.
- In both activities, the mathematics used to determine a relative date on the time line or model can be done as a class, rather than as an individual activity. However, encourage students in later grades to do the math, and use division and remainders to identify the actual date or time for particular events. You can add more events for later grades, corresponding to material already covered in class, like the release of the cosmic background (now microwave) radiation.
- Present the activities as hall displays. Encourage your students to think about how they could explain the model calendar or timeline to others. One way is to annotate each event, and include what evidence astronomers and scientists have to support their estimates. For example, the age of the Solar System is based on the radioactive dating of meteorites and moon rocks.
- Have students research a particular era on the model calendar or timeline, and develop a more detailed "inset" or "zoom-in" view. For example, the age of dinosaurs from 200+ million years ago to about 65 million years ago could be broken into specific geological and biological periods (Triassic, Jurassic, Cretaceous, etc.).

Cosmic Calendar

January
happy
1st
new year

by Therese Puyau Blanchard and the staff of Project ASTRO at the Astronomical Society of the Pacific

Introduction

While there is currently some controversy about the exact numbers, astronomers estimate that the universe began some 12 to 20 billion years ago in the explosion of space, time, matter, and energy we call the Big Bang. Such numbers are hard to visualize. Despite the fact that the national debt is even larger, most students have difficulty grasping how large a span of time this is compared to their own lifetimes or to the events they read about in history.

One way to visualize large expanses of geological or astronomical time is to draw an analogy between the time since the creation of the cosmos and a more familiar span of time. Geology educators have used this technique for a while, but in astronomy the idea was pioneered by Cornell University astronomer and popularizer of science, Carl Sagan.

In Chapter 1 of his Pulitzer-prize winning book, *The Dragons of Eden* (1977, Random House hard cover; Ballantine paperback), Sagan proposes compressing the history of the universe into one year and then seeing where in that year various events of interest fall. Based on this model, Sagan calculates that if the Big Bang takes place at the first moment of January 1, the origin of our solar system will be in mid-September, and the first appearance of humans on the Earth does not take place until late evening on the 31st of December.

Aims:

1) To help students visualize the immensity of cosmic time since the Big Bang

2) To give students practice with ratios and proportions

The Activity

Suggested Grade Level: 4-9

Estimated time to complete: 40 minutes

Materials needed:

12-month calendar

Clothesline and clothespins (optional)

Cosmic Calendar

Some Dates to Remember

Big Bang
15 billion years ago
January 1

Galaxies
13 billion years ago
February 9

Globular Clusters
12 billion years ago
March 14

Solar System
(our Sun and planets)
4.5 billion years ago
September 13

First Life on Earth
4 billion years ago
September 25

Marine Plant and Animal Life
560 million years ago
December 18

Dinosaurs
248 million years ago to 65 million years ago
December 25 to December 30 at around 10 a.m.

Homo Sapiens
200,000 years ago
December 31, approximately 11:53 p.m.

Note:
These dates are approximate. Your students may want to research the latest information about when various events are thought to have occurred.

Large cards or signs for each major event, with the date of the event written on the back (covered by a sheet of paper)

Per Group:

Cosmic Calendar hand-out

Large sheet of construction paper

Glue

Scissors

Procedures

1. Present the concept of a time line by displaying the 12-month calendar hung along a wall or across the room on a clothes line.

2. Explain that January 1st of our one-year "Cosmic Calendar" represents the "Big Bang," which scientist theorize is the beginning of cosmic time. Explain that "today" is represented by the last possible moment on December 31st.

3. Depending on your students' background, brainstorm about some of the important events that happened between the Big Bang and now.

3. Divide the class into groups and distribute a Cosmic Calendar hand-out to each group. Have groups cut and paste the calendar on to the large piece of construction paper to create one long time line.

4. Each group should then cut out the major events listed on the Cosmic Calendar hand-out and decide on the probable order of occurrence. Have the groups place each event next to the month they predict the event occurred. Groups that finish first can predict the day of the month also.

5. Then, select a volunteer group to be a "living time line." Give each person in the group a larger sign or picture of one of the major events (on the back of which you have put the Cosmic Calendar date for that event) and have the students stand under the large time line in the order decided on by the group.

6. Hold a class discussion on the order of the events portrayed. A student who disagrees with the order of a certain event may change places with the person holding that card. Continue the discussion until a majority of the students agree with the order.

7. Have each person in the "living time line" uncover the appropriate date on the back of their card and position themselves on the time line.

8. Point out significant events and discuss these questions:

- Humans arrived on the scene about 7 minutes ago according to our model. How does this change your perspective on our importance?
- Dinosaurs ruled the Earth for almost two hundred million years—from December 25 to December 30 (10:00 a.m.) on our time line. How does this change your thinking about dinosaurs?
- How old is our Sun compared to other stars? If there are older stars than the Sun out there (and there are many), might they have older life-forms on them?
- What might we be like today if hominids on Earth had evolved a million years earlier?

Extensions

1. Have students design their own cosmic time lines in their notebooks, and include information and scale drawings.

2. Have students work in groups to design mobiles using hangers and string.

3. Enlarge a part of the Cosmic Calendar to study the various geological time periods.

4. Designate an entire hall in the school as a cosmic time line. Have students create drawings and captions to describe the major events and hang these along the time line. Have one group make a poster to explain the time line concept to other students.

5. Add additional events to the time line. See the extension below for a ratio to use to figure out the model calendar date for the event.

Extensions for Older Students (Grades 7-9)

1. After students have been introduced to the idea of compressing the events since the Big Bang into a single year, have students brainstorm about some of the most important events that happened between the Big Bang and now.

2. Have students do library research to determine how long ago the various events they have selected happened. Each student or group can be responsible for a manageable number of events to research. If time is short, you may need to provide the times associated with the

Other Possible "Dates to Remember"

Oldest Fossils

3.5 billion years ago

Air-breathing Life

1 billion years ago

Tyrannosaurus Rex

150 million years ago

Supernova 1987A

Explosion as seen in the Large Magellenic Cloud (where it happened)

169,000 years ago

First Human Hunter-Gatherer Societies

30,000 years ago

major events in cosmic history.

4. Have students calculate where in the model calendar year the various events will be placed. To do this, students will need to know the age of the universe. You might have students research this, or use 15 billion years (the value Sagan uses in his book). Note that this is currently under debate as new data comes in from the Hubble Space Telescope and other instruments.

Then have students set up a ratio in the form:

$$\frac{\text{number of years ago event happened}}{\text{number of years ago Big Bang happened } (15 \text{ X } 10^9)} = \frac{x}{365 \text{ days}}$$

Solving for x, students can calculate the number of days counting backward from the end of the year for the event in question. Then they can count back the days on a calendar, starting with December 31 to find the date that corresponds to x days. (Note: If the year of the calendar they are using is a leap year, substitute 366 days for 356 above, or cross out Feb. 29 on their calendars!)

Example:

Galaxies formed 13 billion years ago. Set up a ratio between these dates and the 365 days of the calendar year.

$$\frac{13 \text{ X } 10^9}{15 \text{ X } 10^9} = \frac{x}{365 \text{ days}}$$

$x = 316.5$

So the formation of galaxies in our calendar year happened 317 days before the present (Dec. 31). Thus we must count back 317 days from Dec. 31.

5. The ratio above works well for periods of time that are significant fractions of the age of the universe (such as the formation of the solar system or even the origin of life on Earth). But when you get to events closer to our time (such as the launch of the first satellite from Earth), days are too large a subdivision, and you will need to develop a scale of hours on December 31 of the model year. To do this, subdi-

vide the last day into 24 parts, and maybe even divide the last of those 24 parts into 60 subdivisions. Here is a formula to use (older students can be asked to derive it):

$$\frac{\text{Number of years ago event happened}}{15 \times 10^{9}} = \frac{x}{5.256 \times 10^{5}}$$

Where x is the number of minutes before midnight on Dec. 31 of our Cosmic Calendar.

6. Be sure to leave time to discuss the results of the activity, and give students the opportunity to voice their awe about how small a part of the model year human life and activity takes up. On the cosmic time-scale the story of the human race has just begun. How do students feel about that? If we are very young additions to the universe, how should that influence our behavior?

Cosmic Calendar *Student Worksheet*

Big Bang

First Life on Earth

Homo Sapiens

Solar System
(our Sun and planets)

Dinosaurs

Galaxies

Marine, Plant, and Animal Life

Globular Clusters

JULY

S	M	T	W	T	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

AUGUST

S	M	T	W	T	F	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

SEPTEMBER

S	M	T	W	T	F	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

OCTOBER

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

NOVEMBER

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

DECEMBER

S	M	T	W	T	F	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

JANUARY

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

FEBRUARY

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28				

MARCH

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

APRIL

S	M	T	W	T	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30						

MAY

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

JUNE

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	

Timeline and Scale Model of the Age of the Earth

by Peter H. Burkey and the staff of Project ASTRO at the Astronomical Society of the Pacific

Materials needed:

Adding machine tape

Calculator

Pencil or marker

Procedures

1. Measure and cut 10-meter long strips of adding-machine tape (available at most larger stationery stores). Distribute a strip of adding machine tape to each student group, or create the time line as a class. Have students divide the 10-meter long strip into meters and smaller scale markings.

2. Have students determine the scale for the events on the hand-out. You might also have students research when the events occurred, or add other events.

How to determine the scale

Most scientists agree that the approximate age of the Earth is 4.5 billion years. Use the following ratio to determine the scale for the time line.

$$\frac{\text{number of years ago event occurred}}{4.5 \text{ X } 10^9 \text{ billion years}} = \frac{\text{distance from "present" end}}{\text{length of strip}}$$

Aims:

1) To help students visualize the time span of the evolution of the Earth

2) To use a time line as a scale model

3) To practice ratios and proportions

The Earth's "Cosmic Calendar"

Formation of Earth
January 1

Earth's crust forms
January 2

First living organisms
March 6

Plants and animals develop
October

Coal supply forms
November

Dinosaurs are abundant
December 1

Dinosaurs disappear
December 20

Human species appear
December 31

Roman Empire at peak
December 31, 11:59:30 p.m.

New World discovered
December 31, 11:59:52 p.m.

Hiroshima
December 31, 11:59:59.7 p.m.

For example:

Continental drift began approximately 200 million years ago. To represent this on a time line 10 meters long, complete the following proportion:

$$\frac{200 \text{ X } 10^6 \text{ years}}{4.5 \text{ X } 10^9 \text{ years}} = \frac{x}{10 \text{ m}}$$

$$x = \frac{(200 \text{ X } 10^6 \text{ yrs})(10 \text{ m})}{4.5 \text{ X } 10^9 \text{ yrs}}$$

$$x = .44 \text{ m}$$

$$x = 44 \text{ cm}$$

3. Enter the events on the time line as the proportions dictate. Use the attached handout to find the times of certain significant events in the history of the Earth.

Extensions

- You may wish to expand the last million years on a separate time line using a slightly larger scale to emphasize recent events.
- As an extension of the time line activity, you can relate the age of the Earth to a calendar year (similar to the Cosmic Calendar activity). See the time scale at [left or right] where one "year" is equal to 4.5 billion years.

To create a calendar of you own, use the following proportion:

$$\frac{\text{time}}{365.25 \text{ days}} = \frac{\text{event}}{4.5 \text{ X } 10^9 \text{ years}}$$

Enter the "event" as the number of years ago that an event occurred and solve for "time." Subtract this many days from the end of the year to determine the calendar date on which the event occurred.

Selected Important Events in the Earth's History

EVENT	NUMBER OF YEARS AGO	DISTANCE FROM PRESENT END OF 10 M STRIP
Oldest rocks	3.7 billion	8.22 m
Oldest fossils	3.5 billion	7.78 m
Volcanic activity on Moon ceases	3.0 billion	6.67 m
Photosynthesis begins	2.0 billion	4.44 m
Beginning of plate tectonics	1.5 billion	3.33 m
Oxygen builds up in atmosphere	600 million	1.33 m
First vertebrates appear	500 million	1.11 m
First land amphibians and insects	400 million	89 cm
Rise of reptiles	300 million	67 cm
Age of dinosaurs	200 million	44 cm
Great diversity of mammals	65 million	14 cm
Flowering plants widespread	5 million	1.1 cm
"Lucy"	3.5 million	8 mm
Homo habilis, ice ages	2 million	4 mm
Homo erectus	1 million	2 mm
Neanderthal	130 thousand	.3 mm
Cro-Magnon	35 thousand	.08 mm

HOW MANY STARS?

ACTIVITY H-3

GRADE LEVEL: 7-9+

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What's This Activity About?

How can we help our students grasp the enormousness of a galaxy of stars? Astronomers often use 200 billion as the approximate number of stars in our Milky Way Galaxy, but most of us really cannot "appreciate" a number that large. Counting to 200 billion, at one number a second, would take almost 6,400 years! And a stack of 200 billion pennies, aside from equaling 2 billion dollars, would stretch 286,000 km, or three-fourths of the distance from the Earth to the Moon.

This activity will help students develop a sense of number scale, understand the concept of volume, and develop scientific estimation, measurement and data analysis skills.

What Will Students Do?

Students either create a standard cubic centimeter box, or use a graduated cylinder to count grains of sand. Students first estimate how many containers are required to hold 200 billion sand grains, and then work in groups to count. Once they have determined the number of grains/cubic centimeter, they determine the volume needed to hold 200 billion grains.

Tips and Suggestions

- The extensions close with a statement about the relative spacing of stars, if they were indeed the size of grains of sand. Have students do this calculation as homework, using the same math skills developed in this lesson. For grains about 1.3 mm on a side, the average spacing of stars in our solar neighbor hood would place the grains about 40 miles apart!

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Number of stars in our galaxy	Calculating	Scale
Volume	Recording	
	Inferring	

HOW MANY STARS

BY ALLEN L. KRONE

KEY QUESTION

If stars were each the size of a grain of sand and piled together, how large a cube could be filled by the estimated 200 billion stars in our galaxy?

POSSIBLE PRECONCEPTIONS

The volume of 200 billion of anything is difficult for most people to grasp. When asked the volume of 200 billion of a given object, people will grossly overestimate or underestimate the volume.

KEY CONCEPT

This activity focuses primarily on helping students grasp the enormous size of our galaxy.

METHOD

Students will use grains of sand to represent stars. They will count the grains of sand that fill a cubic centimeter, then calculate the volume needed to hold 200 billion grains of sand.

PROCEDURE

Preparation

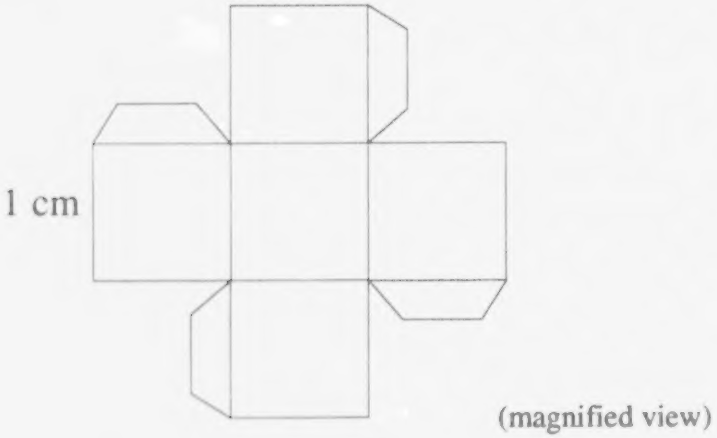
Decide if you want your students to use a graduated cylinder or their own three-dimensional cubic centimeters to scoop up one cubic centimeter of sand. Many students are not aware that one milliliter is equal to one cubic centimeter. If you decide to have your students make their own one-centimeter cube, have them do so the day before they do the activity using the following procedure:

Make a transparency of the centimeter cube template in figure 1, and demonstrate the construction of a cube.

The day before your students work with the sand, have each group pick up one metric ruler, one pair of scissors, and two sheets of scratch paper or graph paper. Tell the groups to use the metric

FIGURE 1

Centimeter cube template



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rulers to draw the template (accurately) on their paper using the template projected from the transparency as a reference. Tell your students to cut around the outer edge of the template, fold along the inner lines, and glue the tabs to make a one-centimeter cube open at the top.

Do the activity and calculations yourself before trying it with your class! You need to know how large a resultant volume to expect. This volume can vary drastically depending on the size of the sand grains you are using. The size of the sand grains also affects the length of time the activity takes to do, which needs to be determined in advance. Students may need anywhere from 5 to 30 minutes of counting time, depending on the size of the sand grains. About 10 minutes is needed for one-millimeter diameter sand grains.

Make a set of three demonstration cubes: one each of 1 cm, 10 cm, and 1 meter on a side. You can make the cubic-centimeter cube using the template above. Make a similar template for the 10-cm cube. You can tape meter sticks together to make a cubic-meter cube, but you will need 12 of them!

Filter the sand using a set of screen sieves to eliminate the finer grains. The sand does not need to be uniform, but all the grains need to be large enough to be easily counted. A diameter of one millimeter, on average, works well. If you do not have a sieve, separate the sand by suspending it in water; the larger grains will settle preferentially to the bottom. If you use this method, do it far enough ahead of time to allow the sand to dry (about two days).

Introduce your students to the structure and scale of galaxies before beginning the activity. This introduction may be handled in many different ways and may combine such elements as class discussion, homework reading selections, viewing and discussion of a video (see Appendix), viewing of slides and photographs, and so on. (See the activities *Counting to a Billion* and *Galaxy Shapes* elsewhere in this manual.)

Your objective with this introduction is to expose students to basic information such as: the description of a galaxy; the general structure of galaxies; and the name of our own Galaxy, the Milky Way.

General Information

Target Grades:	Upper Middle to High School (Grades 8 – 12)
Participant Size:	Groups of 2 or 3
Length of Activity:	60 – 90 minutes
Where:	Inside
When:	Anytime
Method:	Teacher-guided discovery, problem solving
Focus:	Scale, distances, galaxies, light years
Skills:	Interpreting data, observing, modeling, using numbers, predicting

Materials List

Per group of students:

Medium to coarse sand, about 200 ml, sifted to obtain fairly large grains

1 meter stick

1 graduated cylinder (needed if paper cube is not made)

Optional: for students to construct their own cubic centimeter:

2 sheets of paper (scratch/recycled paper is fine, as is 1 cm graph paper)

1 metric ruler

1 scissors

1 glue stick

Teacher supplies:

Demonstration cubes: 1 cubic centimeter, 10 cubic centimeters, 1 cubic meter (see Preparation)

Optional teacher supplies:

Overhead transparency of centimeter cube template (template provided)

Screen sieves (can be obtained from an earth science class)

Videos: *So Many Galaxies, So Little Time*, or *Powers of Ten* for optional pre-activity viewing (see Appendix for ordering information)

Overhead projector instead of chalkboard

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Doing the Activity

Tell your students that our galaxy, the Milky Way, consists of about 200 billion stars. Ask several students to explain their concept of how big a number that is. (Note: no one has counted [or could count] all the stars in our galaxy—most are not visible to us. This number is a very rough *guess*. The correct number might be several times larger or several times smaller and, in fact, keeps changing as stars are born and die.)

Ask students how big a crate they would need to store 200 billion bricks. (A crate about 525 m on each side) If a shopping mall were to have a "guess-the-number-of-jellybeans" contest using a cylindrical jar filled with 200 billion jelly beans, what would the jar's height be if its diameter were one meter? (Roughly 500 kilometers, assuming 2 cc per jellybean) The responses should make the point that students may know that 200 billion is 200 thousand million, but they are not likely to have any idea of the space that would be occupied by that many objects.

Establish the goal of the activity by explaining that one of the most important benefits of a study of astronomy is an appreciation for the vastness of the cosmos. One cannot appreciate how immense our galaxy is just by saying that there are 200 billion stars in it, because most people do not have an accurate notion of how big that number is. Share this rationale for the activity with your students (see Possible Preconceptions).

Tell the students that this activity will help them gain a better understanding of how many stars 200 billion really is. Ask them to imagine that they can take every star in our galaxy and scale it down until it is the size of a grain of sand. Sand grains vary in size—and star sizes vary far more drastically—but tell them to imagine that the average star has been shrunk to the average size of a grain of sand which will be used during the following experiment as a model for a star.

Count out 5 or 10 sand grains onto a table, and ask the students to imagine that they continue to count out "stars" until all 200 billion of them have been piled into a cube. Ask your students to estimate how big a cube would result.

Show the class the one-cubic-centimeter cube and the 10-cubic-centimeter cube and ask the students to estimate how many of each such cubes would be needed to hold 200 billion grains of sand in total. Each student should record her/his estimates for later reference. Ensure that each student writes down the two estimates. Now select several students to share their estimates with the class and record these on the board. Estimates typically range from 0.1 to 100,000 cc, with a few students forgetting the rules and guessing that the sand would cover the whole table or perhaps even spill over onto the floor.

Now explore with your class the question of how big the pile would be by requesting that they count the number of "stars" (i.e., grains of sand) in that one cubic centimeter, and then have them use proportional reasoning to find what volume 200 billion such stars would occupy.

Combine your students into groups of two to three students each and have each group pick up one cubic centimeter of sand by using the cubic centimeter they made previously or by using a graduated cylinder.

When the groups return to their tables, each group should dump their "stars" onto a second sheet of scratch paper and use this as a counting surface. Suggest that the groups *do not* count one by one out loud; instead suggest that they push the sand grains into groups of ten, and then count the number of groups of ten.

Record the total count of sand grains from each group in the class, and together with the class calculate a class average for the number of stars in one cubic centimeter.

Divide the total number of stars, 200 billion, by the class-average estimate of the number of stars per cubic centimeter. The resultant number is the volume of the pile of stars in cubic centimeters. That answer, however, is still large to the point of being meaningless. A larger unit is needed to express this larger volume in a manner that will be more meaningful to the students.

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Using the demonstration 1000-cubic-centimeter cube and 10 of the one-cubic-centimeter cubes, tell students that one liter = 1000 cubic centimeters. The numerical value of the volume of our pile of stars expressed in liters is 1000 times smaller than when expressed in cubic centimeters. You will find that this number is still too large to be meaningful. An even larger unit of volume is needed.

Use the demonstration one-cubic-meter cube and the one-liter cube when telling students that one cubic meter contains one thousand liters or one million cubic centimeters. Thus, your students need to divide their individual results, or the class average, by one million (10^6) to get the volume of the pile in cubic meters. While the results depend entirely on the size of the sand grains being used, your students will generally find that all the stars in our galaxy would be represented by a pile of sand which has a volume of about 500 cubic meters—enough to fill a very large classroom to the ceiling!

With that fact in mind, have your students measure the dimensions of your classroom and calculate the room's volume in cubic meters.

Closure

After this visual image has had some time to sink in, remind students of the true sizes of stars. (Most stars like the Sun have an equatorial diameter of about one million kilometers.) Furthermore, within our galaxy, stars are *many* trillions of kilometers apart. With this information, your students may finally begin to have some sense of just how big our galaxy is.

EXTENSIONS

Discuss the relationship between the number of stars in our galaxy and the number of stars in the universe. Ask your students to contemplate the fact that there are about as many galaxies in the universe as there are stars in our galaxy. Have them calculate the approximate number of stars in the universe on the assumption that every galaxy has about the same number of stars.

You may wish to do one of the following extensions each day—perhaps to begin each day—so as to encourage students to think further and to promote better long-term memory.

Have your students change the scale for a star so that some larger object, such as a baseball, represents a star, and have them calculate the volume of the resulting cube of 200 billion baseballs. This calculation may proceed as follows: estimate the volumes of a grain of sand and of a baseball; divide the latter by the former, and multiply the result by the volume occupied by the 200 billion grains of sand. The resultant number is the volume of 200 billion baseballs.

Have your students find the volume of sand which would be needed to represent all of the stars in the *universe*. Rather than having your students use cubic meters, suggest an original, more *meaningful* volume unit, such a domed stadium, for their use in expressing the volume.

In this activity an individual star is envisioned as shrunk in size to that of a grain of sand; these grains are then piled up without regard to the true spacing between the stars. Point out and emphasize to the students that the sizes of their piles did *not* represent the size of the galaxy itself which is far, far larger. Ask the class to now visualize that our galaxy is placed in a "shrinking machine," which shrinks everything—both stars and interstellar distances—and continues the shrinking of the galaxy until an average star is again the size of a grain of sand. Ask for predictions of the volume of this shrunken galaxy, and then calculate this volume with the class.

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BACKGROUND

Galaxies vary in size and structure, but our Milky Way galaxy is typical of the spiral type and has a typical number of stars, about 200 billion (2×10^{11}). In the same way that virtually all stars are grouped in galaxies, most galaxies are grouped into galaxy clusters, and clusters are often grouped into superclusters. The universe contains more than 100 billion galaxies, most containing 100 billion or so stars (see Appendix for sources of information on galaxies).

It is not sufficient to simply tell students that the Milky Way galaxy consists of 200 billion stars, because the number is meaningless to them and they will not even begin to appreciate just how large a number of stars that is. Their internal ("gut") sense of scale needs to be refined, and that is the objective of this activity.

This comprehension is an important objective because, if a student understands the vastness of the universe of which s/he is a part, that knowledge forever changes the student, broadening and enriching her/his perspective of the world.

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A BALLOONING UNIVERSE

ACTIVITY H-4

GRADE LEVEL: 8+

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What's This Activity About?

Does the universe have a center? What does it mean when astronomers say that the universe is expanding? How do astronomers measure that expansion? These questions are at the heart of cosmology, and they are often stated to our students without giving them the chance for some hands-on exploration. This simple activity helps students to "feel" the universe expanding and to develop their own personal understanding of an expanding, infinite universe. Along the way, the activity models the process of scientific measurement and data analysis, and it paves the way for the following activity on Hubble's Law.

What Will Students Do?

Students, working in pairs, put marks on a balloon to represent galaxies, measure and record the distance between marks, and then inflate the balloon. Repeated measurements as the balloon inflates demonstrate how the universe could expand, with all galaxies receding from each other. Students report their results to the class and discuss questions about their model.

Tips and Suggestions

- Although the expanding balloon analogy works well to demonstrate how galaxies move away from each other, it may lead students incorrectly to believe that the galaxies themselves are expanding, too, as the ink dots on the balloon stretch out. It is important to stress that space itself is expanding, not galaxies nor the matter they contain. The Milky Way does not seem to be getting larger each year, nor is our solar system growing because the universe is expanding.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Expansion of the universe	Exploring	Scale
	Observing	Models
	Measuring	Patterns of Change
	Inferring	

A Ballooning Universe

It is difficult for many students to understand the idea that the universe can extend infinitely in all directions and still be expanding. The students grapple with this concept by making a "curved two-dimensional" balloon model of the universe.

Materials

- ☐ Balloon (1/pair of students)
- ☐ Marking Pen (1/pair of students)
- ☐ Tape Measure (1/pair of students) or a "Do-It-Yourself Tape Measure" (master on page 42), scissors, and tape for each pair of students
- ☐ Blank sheet of paper, 8.5"x11" (1/pair of students)

Before Class

If you don't have ready-made tape measures, photocopy a "Do-It-Yourself Tape Measure" (master on page 42) for each pair of students. This can be made into a double master so that you can chop the photocopies in half lengthwise to get twice the number of tape measures.

In Class

1. Imagine a universe of many galaxies distributed throughout space. We can make a two-dimensional model of that universe by drawing galaxies on the surface of a balloon.

2. Hand out a balloon and pen to each pair of students. Have them take turns drawing several galaxies on the balloon. Have them mark a unique name (or number or letter) by each galaxy that they draw.

3. Hand out a tape measure for each team. Alternatively, hand out the "Do-It-Yourself" sheet with scissors and tape for each team. They can cut and tape the ruler strips from sheet into one long strip to be used as a "paper tape measure" for measuring the distance around the balloon.

4. Have each student draw a "Distance Table" on a blank sheet of paper and label the rows:
"Distance 1—Between Galaxy ___ and Galaxy ___,"
"Distance 2—Between Galaxy ___ and Galaxy ___,"
"Distance 3—Between Galaxy ___ and Galaxy ___,"
and "Circumference of Universe_____."
There should be three blank columns.

5. Have one student in each team blow up the balloon so that it just barely starts to inflate, then hold the neck of the balloon pinched between two fingers so that it does not lose air. Have the second student of the team measure the separations between three pairs of galaxies on the balloon and record the galaxy names and distances in the Distance Table. The second student also measures the distance around the balloon with the tape measure and records that distance in the last row of the table. The first student of the team can then release the balloon and copy the measurements onto his or her own Distance Table.

6. Ask the students to predict what the distances between the galaxies will be if they expand their balloon universe to twice the size that it was for their first measurement. Have them write their predictions by the distance entries that they recorded in their Distance Tables.

7. To see if their prediction is correct, one student holds the paper tape measure in a loop twice as big

	Measurement 1	Prediction	Measurement 2
Distance 1—Between Galaxy ___ and Galaxy ___			
Distance 2—Between Galaxy ___ and Galaxy ___			
Distance 3—Between Galaxy ___ and Galaxy ___			
Circumference of Universe			

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as the circumference of the balloon in their first measurement. The other student blows up the balloon to fit. It may take a few tries to get it just right. Once the balloon fits the right circumference, the balloon blower pinches the neck of the balloon to keep air from escaping, while the other team member measures the distances between the same three pairs of galaxies as were measured before, and records the measurements in the table.

8. Have teams report their results.

9. Ask for conclusions with the following questions:

Are all the galaxies moving away from one another? (Yes.)

Is there any "center" on the surface of the balloon? (No. The center inside the balloon doesn't count because two-dimensional people living on the two-dimensional surface would not be able to go to that center.)

What are the weaknesses in our model of the universe?

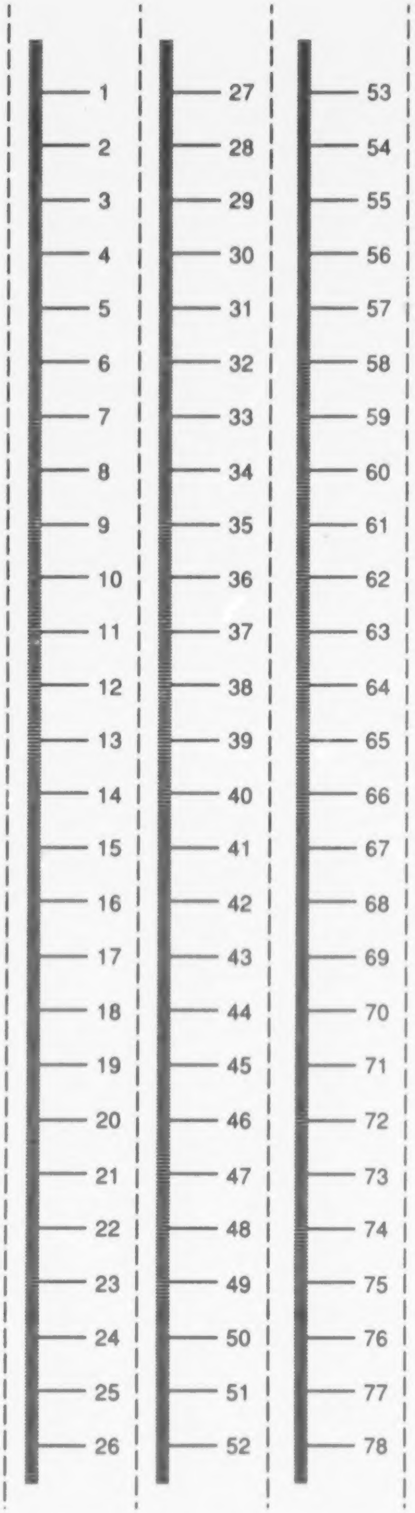
In what ways might our balloon universe model be different from the real universe?

[Background for the teacher: The real universe is not like the surface of a balloon; the universe has 3 dimensions of space, not just two; the universe is expanding in Einsteinian "space-time," a FOUR- dimensional space that is not at all reasonable to common sense; the galaxies themselves are not expanding (the way they do on the balloon; it is the time and space between them that is expanding. One similarity: the real universe does not have a center, any more than the 2-dimensional surface of the balloon has a center. See Abbott's *Flatland* and any of the excellent popularizations of cosmology for more information.]

In the real universe, evidence shows that all galaxies are moving away from each other. ***Will our universe expand forever or will it stop expanding a start collapsing someday?*** (No one knows. Scientists today are carefully measuring the rate of expansion, and may soon be able to determine what the fate of theuniverse will be.)

Going Further

Have your students select a galaxy on the balloon to represent our Milky Way galaxy. Point out that the Milky Way is not at the center of the universe, since there is no center on the balloon's surface. Have the students measure and record the distances from the Milky Way to all the other galaxies when the balloon is small, and again when the balloon is large. The changes in distances can be used to help in understanding Hubble's Law (Part D of the next activity, The Expanding Universe).



A Ballooning Universe — Do-It-Yourself Tape Measure

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THE EXPANDING UNIVERSE

ACTIVITY H-5

GRADE LEVEL: 8-9+

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What's This Activity About?

This activity is a very thorough investigation of the physics of waves, the Doppler Shift principle, and the nature of Hubble's Law. It progresses smoothly from a demonstration of wavelength of string waves to sound waves, and finally makes an analogy to light waves, which will help students understand that the physics of wave behavior applies to all kinds of waves.

What Will Students Do?

First students use long springs (or long elastic ropes) to investigate the frequency and wavelength of various waves. Students then observe a demonstration of the Doppler effect for sound waves, as a continuous sound source is whirled in a circle. Then students use their understanding of the Doppler shift applied to light to investigate the shifted spectra of sample galaxies. Finally, students use their data to create a graph of distance versus recession speed, illustrating Hubble's Law.

Tips and Suggestions

- This activity should follow an experiment or demonstration on the emission spectra of gases, so that students will understand how the Doppler shift is measured with light. It is most suitable for advanced students in grades 8-9, but also appropriate for high school physics classes.
- Consider accompanying this exercise with sections from the video, *So Many Galaxies, So Little Time* by Margaret Geller, about her work with John Huchra of Harvard mapping slices of the universe (available from the educational catalog of the Astronomical Society of the Pacific).

What Will Students Learn?

Concepts

Wavelength
Frequency
Doppler shift
Hubble's law
Expansion of the universe

Inquiry Skills

Experimenting
Graphing
Observing

Big Ideas

Energy
Interactions
Patterns of Change

The Expanding Universe

What is the evidence that our universe is expanding? These activities will help students understand how we know that the universe is expanding. It is important for your class to have already done activities on light spectra, such as those in *PASS Volume 8, Colors from Space*, pages 32–43. Once your students are familiar with light spectra, they can understand the idea of Doppler shift by first hearing the acoustic Doppler effect from revolving sound generator. They can then relate redshift of galaxies' spectra to the galaxies' velocity away from us. Finally, your students make a graph of distance vs. velocity for a number of galaxies to find the "Hubble constant" of our expanding universe.

Materials

For Part A

☐ One long snaky spring. (Available through science supply companies such as Frey Scientific (in Mansfield, Ohio).

☐ A clock with a second hand.

☐ Worksheet "Frequency and Wavelength" (1/student; reduced sample on this page)

For Part B

☐ One loud sound generator. An old-fashion alarm clock works well. Or, go to your local electronics store and get a 3v buzzer, two batteries (C or D size) and a battery holder. If you want to get fancy, put a switch on it too.

☐ Rope, heavy-duty fishing line, or very heavy duty string (about one meter long)

For Part C

☐ Worksheet "Spectra of Fast-Moving Galaxies" (1/student; master on page 54)

☐ Pencil (1/student)

For Part D

☐ Worksheet "Hubble's Law" (1/student; master on page 48)

☐ Pencil (1/student)

Frequency and Wavelength

Draw a Single Wave:

Frequency ____________

Wavelength ____________

Draw a Double Wave:

Frequency ____________

Wavelength ____________

Draw a Triple Wave:

Frequency ____________

Wavelength ____________

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Before Class

1. Make a full or half page version of the worksheet shown on this page. Make a photocopy for each student.

2. The snaky spring can be held by looping one finger through an end loop of the spring. However, it is much more comfortable if you make a handle for each end of the spring. The simplest handle is a stick inserted through the end loop of the spring and secured with duct tape.

3. Tie one end of the rope (or string) **securely** to the loud sound generator. It is best to thread the rope through a hole in the sound generator, e.g. holes in the battery holder. Drill a couple of holes if necessary. Use several secure knots. On the other end of the rope, tie a loop that will fit snugly around one of your wrists.

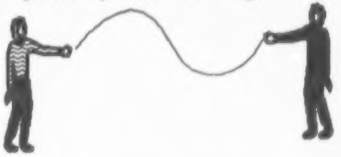
In Class—Part A
Frequency and Wavelength

1. Ask your students, ***"What is sound made of?"*** *(Vibrations of air molecules; or vibrating air)* It may take some discussion for the students to understand that air can vibrate. One excellent exercise is to have the students touch their own voice boxes to feel the vibrations while they hum. To get across the idea that sound waves travel from the source of vibration, through the air, ask, ***"Have you ever heard an echo of a sound that has traveled a long way and bounced back to you?"***

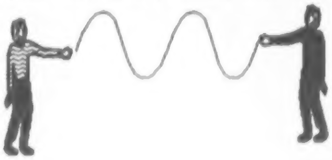
2. Ask a student volunteer to hold one end of the snaky spring tightly and walk at least six paces away from you to stretch the spring out. Have the rest of the class count the number of paces out loud.

3. Remind the volunteer to hold tight while you move the other end sharply up and down once to create a single spring wave that travels down the spring and bounces off the volunteer's hand. Explain that we can imagine the spring to represent air molecules (or air *pressure*, if you wish to be more exact). Sound waves travel through the air very much as the spring wave travels down the spring, but sound waves travel much faster — about 1/3 km/sec

4. Hand out a pencil and a worksheet to each student. Ask the students to watch the shape of the spring wave as you make a single wavelength standing wave on the spring. [A single wavelength will appear to have two crests going up and down alternately. Do not confuse this with a single crest going up and down, like a jump rope, which is really only 1/2 wavelength.] Ask them to draw the shape of the spring wave near the top of their paper. Explain that the length of the wave is called its "wavelength." Ask the students to write down the wavelength (in "paces") in the appropriate spaces by their drawings.



5. Have the students count how many times your hand moves up and down in ten seconds, as you continue making a single standing wave. Ask them to write the number down next to their wave drawing. Ask, ***"How many times was my hand vibrating each second?"*** *(Divide by 10 the number of vibrations counted in 10 seconds.)* Explain that for any wave, the number of vibrations per second is called the "frequency" of the wave. The unit of frequency is "cycles/sec" also known as "hertz." Ask the students to record the frequency of the wave by their drawings.



6. Now create a standing wave that has two full wavelengths on the spring (two pairs of crests moving alternately up and down). Have the students draw this wave and time it as before, counting how many times your hand goes up and down in 10 seconds. Have them record the frequency and wavelength in the appropriate spaces.

7. If you can move your hand fast enough, make a standing wave with three full wavelengths on the spring and have your students find its frequency as before. They can draw this wave and record its wavelength and frequency on their sheet.

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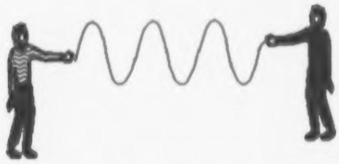

8. Ask, ***"What is the relationship between a wave's frequency and its wavelength?"*** *(Higher frequencies correspond to shorter wavelengths.)*

Part B—Doppler Effect with Sound Waves

1. Ask your students, ***"What is the difference between a high frequency sound wave and a low frequency sound wave?"*** *(This is very difficult to answer by words alone. It is much easier to demonstrate by singing or humming a high pitch note and a low pitch note.)* To illustrate the difference, ask the students to sing or hum the highest pitch sound that they can make. Then have then sing or hum the lowest pitch sound they can make.

2. Tell the students that you are going to make a sound generator with a constant frequency whirl around so that it will alternately be traveling towards them and away from them. Instruct them to listen carefully to the sound to determine if the frequency seems to change. Specifically, ***"How does the sound frequency change when the sound source is coming towards you?" "How does it change when the sound source is going away from you?"***

3. Have the class go to the edges of the classroom while you stand in the center. Hold up the sound generator and explain what it is. Insert your hand through and make sure the wrist loop has a tight fit to your wrist. In addition, hold the rope tightly in your hand. Start the sound generator. Hold it still and have your students listen carefully to the normal pitch of the sound. Then start the sound generator whirling around. For safety, it is best to whirl the sound generator in a vertical circle parallel to the lines of students, so if the device is accidentally released, no one is struck. Let the class listen for a number of revolutions. Ask, ***"Do you hear the pitch changing?" "How does the sound frequency change when the sound source is coming towards you?"*** *(Frequency gets higher.)* ***"How does it change when the sound source is going away from you?"*** *(Frequency gets lower.)*

Write on the chalkboard, "Sound source approaching — frequency higher," and "Sound source receding, — frequency lower."

4. Ask, ***"Have you ever heard this effect before?"*** *(In cars, trains, jets, etc.)*

Part C—Doppler Effect with Light Waves

1. Ask your students, ***"How are light waves different from sound waves?*** *(They are made of different "stuff." They are vibrating electric and magnetic fields rather than vibrating air. They move much faster than sound: 300,000 km/sec as opposed to sound which travels at 1/3 km/sec)* Explain that light waves can exhibit Doppler effect very similar to the acoustic Doppler effect that they heard in part B.

2. Ask your students to recall the order of the visible spectrum colors from previous activities on light spectra *(red, orange, yellow, green, blue, violet).* [Better still, get out the light sources and diffraction gratings again to have students see the spectra.] Explain that violet has the highest frequency of all the visible light colors. Ask, ***"If violet is the highest frequency of visible light, which end of the spectrum has the lowest frequencies of light?"*** *(Red.)*

3. Have your students see or recall the line spectra that they observed for particular elements. Draw the spectrum of hydrogen on the chalkboard as shown below. Explain that hydrogen is the most common element in the universe. Nearly all stars have hydrogen. If we look at the spectrum of a star, we nearly always see the red, turquoise, and violet lines associated with hydrogen, along with other lines that are from other elements in the star. Each color line is a certain frequency of light.

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4. Consider the brightest line in the hydrogen spectrum. If a star is moving towards you or away from you, each spectrum line will be shifted either toward the red or toward the violet end of the spectrum, because of the Doppler effect. Ask, ***"If a star is coming towards us, will its spectrum lines shift towards the red end or the violet end of the spectrum?"*** *(The violet end. If necessary, ask them to recall from the acoustic Doppler effect whether the frequency shifted higher or lower when the sound source was coming towards them. You wrote the results on the chalkboard at the end of Part B.)* Ask, ***"If a star is going away from us, will its spectrum lines shift towards the red end or the violet end of the spectrum?"*** *(The red end.)*

5. Hand out a "Spectra of Fast-Moving Galaxies" worksheet to each student. Explain that it has the Hydrogen spectrum lines of several galaxies. The darkest line in the spectrum represents red. The scales at the top and bottom of the sheet relate Doppler shifts of the galaxies' spectra with velocities of the galaxies. Ask, ***"If a positive velocity means the galaxy is moving away from us, what would it mean if a galaxy had a negative velocity?"*** *(The galaxy would be moving towards us.)* ***"If a galaxy's spectrum is shifted towards the red end of the spectrum, is the galaxy moving towards us or away from us?*** *(Away.)*

6. Challenge the students to figure out how fast each galaxy is moving and write down its velocity in the box by each galaxy. Remind them that a positive velocity means that the galaxy is moving away.

Part D—Hubble's Law

1. Hand out a "Hubble's Law" worksheet to each student. Have them plot a point for each galaxy's distance and velocity as determined on the "Fast-Moving Galaxies" worksheet.

2. ***"How would you describe in words what the graph tells you?"*** Have students write down what they discovered. *(The farther away the galaxy is, the faster it is moving away from us.)*

3. The galaxy distances on the worksheet are derived from the methods described in the planetarium program. The finding that the farther away a galaxy is the faster it is moving away is called the Hubble Law because it was first discovered by astronomer Edwin Hubble.

4. ***"What does Hubble's Law imply about how our universe is behaving?"*** *(Hubble's Law makes pretty good sense only if the whole universe is expanding!)*

5. Assuming Hubble's Law applies for most galaxies, astronomers estimate distances to the most remote galaxies by measuring redshifts, finding velocities, and calculating distances from Hubble's Law. ***How distant is a galaxy that is found to be receding from us at 120,000 km/sec?*** *(About 4 billion LY.)*

Going further

If you did the "Going Further" part of the Ballooning Universe activity, have students refer to distances from the "Milky Way" on the balloon to other galaxies that they measured on the balloon . ***How did distances between galaxies when the balloon was small relate to the distances when the balloon was large? Look the change in distances for galaxies that were close together as compared with galaxies that were farther apart. Was the change in distance larger or smaller for galaxies that were farther apart?*** Point out that galaxies that moved farther away from each other during the time period of the balloon expansion must have been moving away from each other faster.

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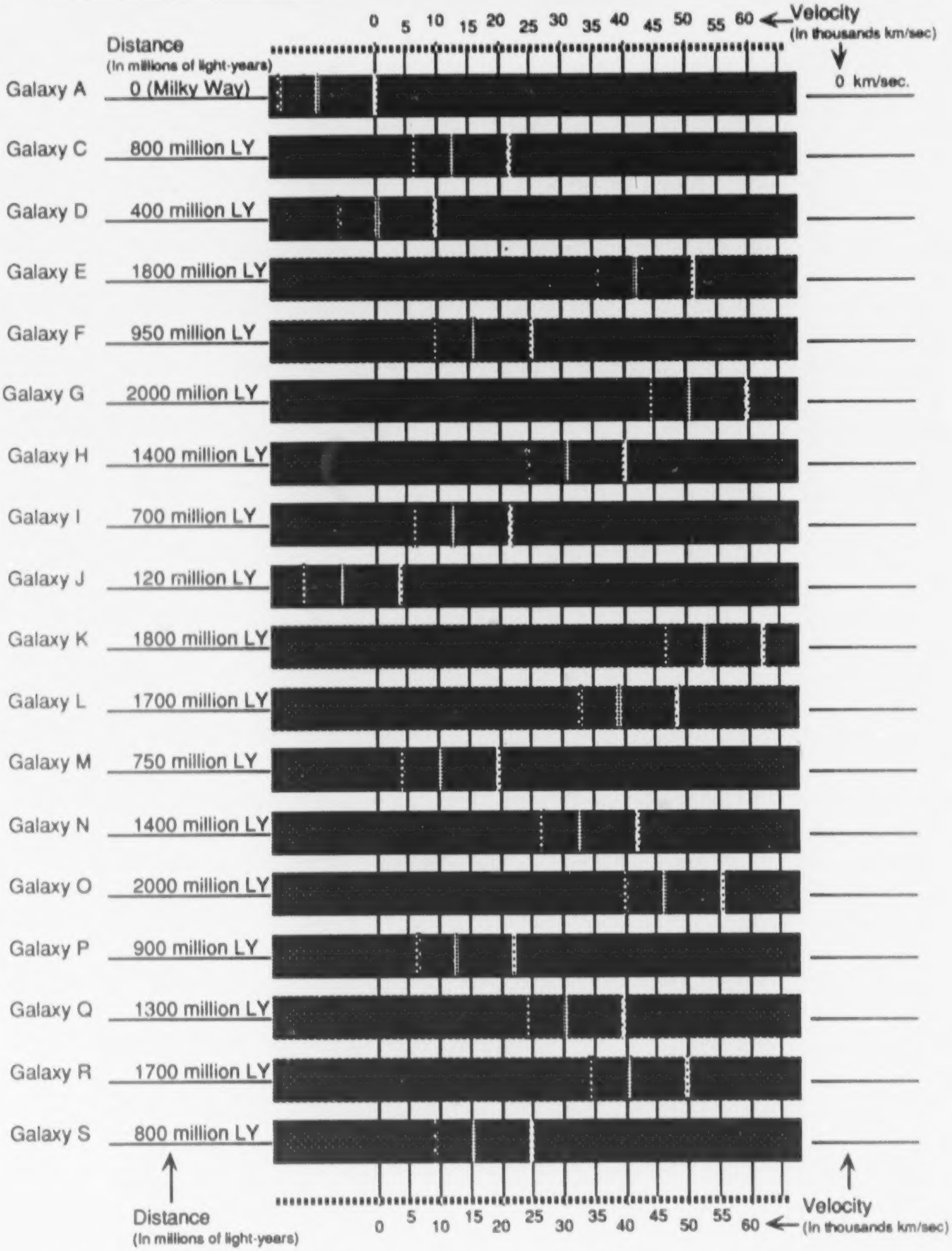
Spectra of Fast Moving Galaxies



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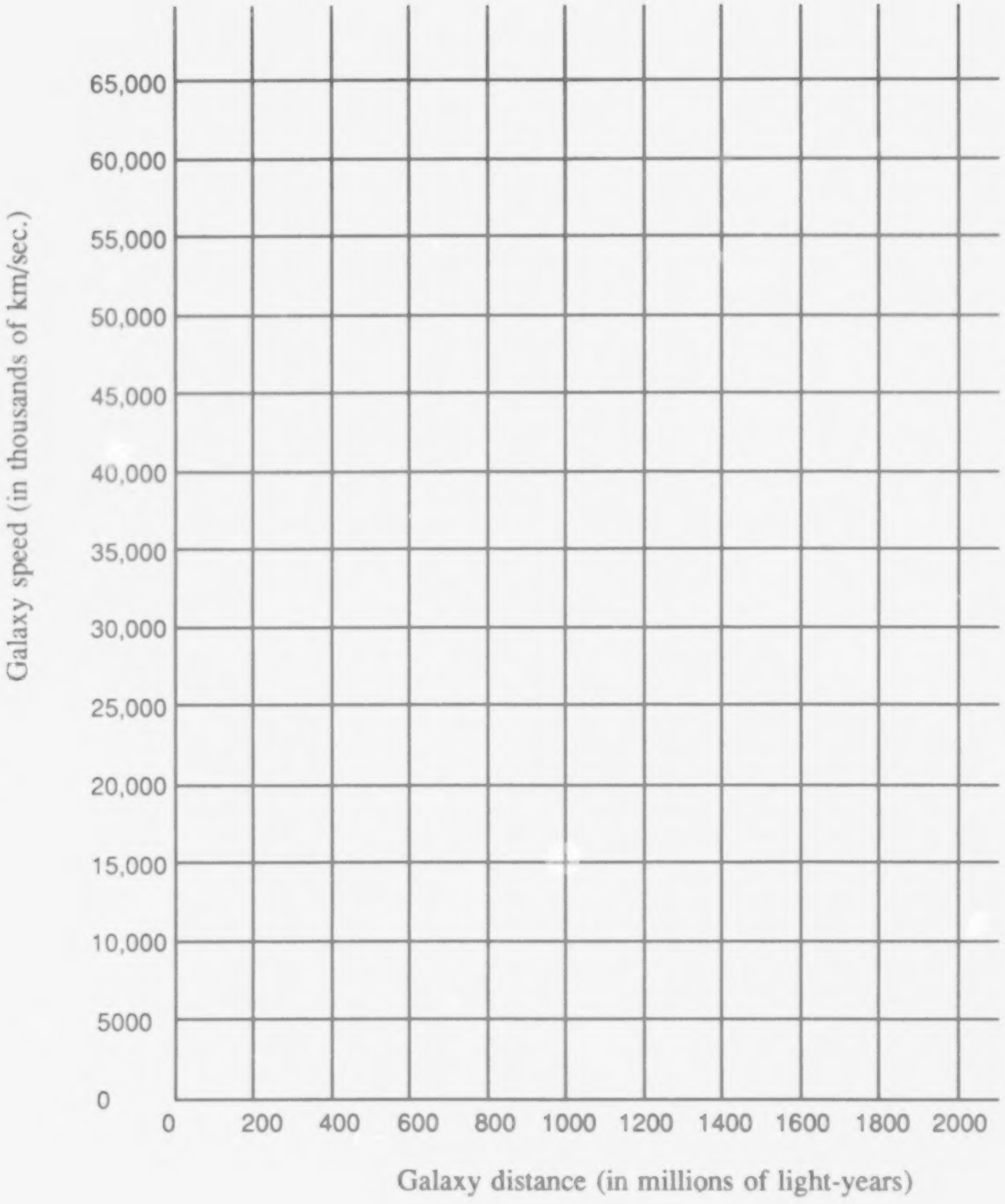
Hubble's Law



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Visualizing the Expansion of Space

Activity H-6

Grade Level: 8-9+

Source: *Visualizing the Expansion of Space* by David Chandler. Transparency Masters were produced with the IBM-PC Program, *Deep Space 3-D,* by David Chandler. The program is available on disk and CD-ROM from David Chandler Co., P.O. Box 309, La Verne, CA 91750. A demonstration version of the program is available for $5.00 ppd.

What's This Activity About?

This exercise uses transparencies to illustrate how the universe seems to be stretching out, with every cluster of galaxies receding from every other cluster. One strength of the activity is that is forcefully demonstrates how there is no special center to the expansion. With some measuring and simple mathematics, students can derive a Hubble's Law relationship from their data. The activity models the process of science quite well, encouraging collaboration and group discussion.

What Will Students Do?

Students use a special set of transparency and master sheets with dots representing clusters of galaxies at two different eras of the universe's history. By aligning the transparency and underlying page, students observe and measure clusters moving away from particular locations. Students graph their data, compute a slope, and relate the slope to the age of the universe.

Tips and Suggestions

- Introduce this activity with a discussion or exploration about the Doppler Shift and spectra.
- To demonstrate this activity for the entire class, make an overhead transparency of each universe map and display both on the overhead projector.

What Will Students Learn?

Concepts
Hubble's Law
Expansion of the universe

Inquiry Skills
Observing
Graphing
Calculating

Big Ideas
Patterns of Change
Simulations

VISUALIZING THE EXPANSION OF SPACE

by David Chandler

The goal of this exercise is to investigate the nature of the expansion of space and to measure the age of a model universe. Using overlaid random dot patterns to simulate clusters of galaxies, students observe and measure clusters "moving away" from particular locations to investigate the age of the universe.

Materials

1. *White sheet of paper with random dots for each student/group*
2. *One transparency with the same dot pattern expanded slightly for each student/group*
3. *A centimeter ruler for each student/group*

Note:

If both dot patterns are put onto transparencies the exercise can be done as a demonstration on an overhead projector.

INTRODUCTION

Early in this century Edwin Hubble discovered that the universe is expanding. Galaxies are moving outward from us, and the farther out they are, the faster they are moving. In fact if you compare the speed of a galaxy with another one twice as far away, the one twice as far out will be moving outward twice as fast. In other words, the speed is proportional to the distance. This effect has become known as Hubble's law. The proportional nature of the expansion has some interesting consequences:

1. We appear to be at the center of the expansion because galaxies are moving away from us symmetrically in all directions. However, observers in other galaxies far away would observe the same symmetric expansion and perceive that *they* were at the center of the expansion. The perception of being at the center is an illusion. There really is no center to the expansion. Everything is moving away from everything else.

2. If we trace the expansion *backward* in time, all of the matter in the universe would arrive at the same point at the same time in the distant past. Matter coming from twice as far away is moving twice as fast, matter coming from 10 times as far away is moving 10 times as fast, so everything catches up at once. It thus appears that the universe got to its present state by expansion from a tiny, hot, dense fireball by what is popularly called the "Big Bang."

By measuring the speed of expansion, the age of the universe can be calculated. One assumption built into this method is that the rate of expansion has remained constant, over time. The rate of expansion is called the *Hubble Constant* and the age of the universe calculated in this way is called the "Hubble Age," generally estimated at 10-20 billion years.

THE ACTIVITY

Give students the hand-out on the next page or use the handout to lead the activity as a class demonstration

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VISUALIZING THE EXPANSION OF SPACE: A SIMULATION

MATERIALS

1 white sheet of paper with random dots

1 transparency with the same dot pattern expanded slightly

A centimeter ruler

The white sheet represents the universe one billion years ago. The transparent overlay represents the universe today. Each dot represents a cluster of galaxies. Evidence from studying the motions of galaxies shows that the universe is expanding at about the rate indicated by these two dot patterns.

1. Inspect each sheet individually. Do you notice any "center" to the pattern of dots?

2. Place the overlay on the white sheet, being careful not to rotate one relative to the other. Note that a very definite center of the pattern appears. Measure the location of the center in centimeters.

Distance (in cm) from the left edge of the paper:____________

Distance (in cm) from the top edge of the paper:____________

3. Shift the overlay without rotating it. What happens to the center point?
Shift it again in different directions. What happens to the center point?

4. Pick a dot. Can you discover how to move the overlay so that any point you choose will become the center? When you are ready, have another student pick a dot for you. Shift the overlay to make that dot the center. Describe your method in words.

5. Each dot represents a galaxy. The dots on the paper represent the universe one billion years ago. The dots on the overlay represent the universe today. Select a dot to be your home galaxy. Line up the overlay exactly so there is no rotation. The separation between a dot on the paper and the corresponding dot on the overlay represents the speed of the galaxy: how far the galaxy has moved in one billion years.

a) What direction are the galaxies moving?

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b) Are all the galaxies moving at the same speed?

c) What pattern do you see in the speed and direction of motion of the galaxies?

6. How long has the universe been expanding? If you know the distance a galaxy has traveled in one billion years and the total distance a galaxy has traveled, you could step off the total distance with the one-billion-year distances to see how many billion years had elapsed. This is the same as dividing the total distance by the one-billion-year distance.

Pick five galaxies at different distances from the center. For each galaxy: 1) measure the total distance it has moved from the center of your expansion 2) measure the distance it has moved in the one billion years (the distance between the 2 dots representing the same galaxy) and 3) divide. The ratio gives you the age of the universe in billions of years. Average your results to get a better estimate.

	TOTAL DISTANCE		DISTANCE IN 1-BILLION YEARS		AGE OF UNIVERSE
1.	________________	/	________________________	=	____________
2.	________________	/	________________________	=	____________
3.	________________	/	________________________	=	____________
4.	________________	/	________________________	=	____________
5.	________________	/	________________________	=	____________

Average Age of Universe = ____________

12. How does your computed age for the universe compare with the age found by other students who used different center dots for their home galaxy? How would you account for differences in your answers? Do you think astronomers in distant galaxies would agree with astronomers on earth about the age of the universe?

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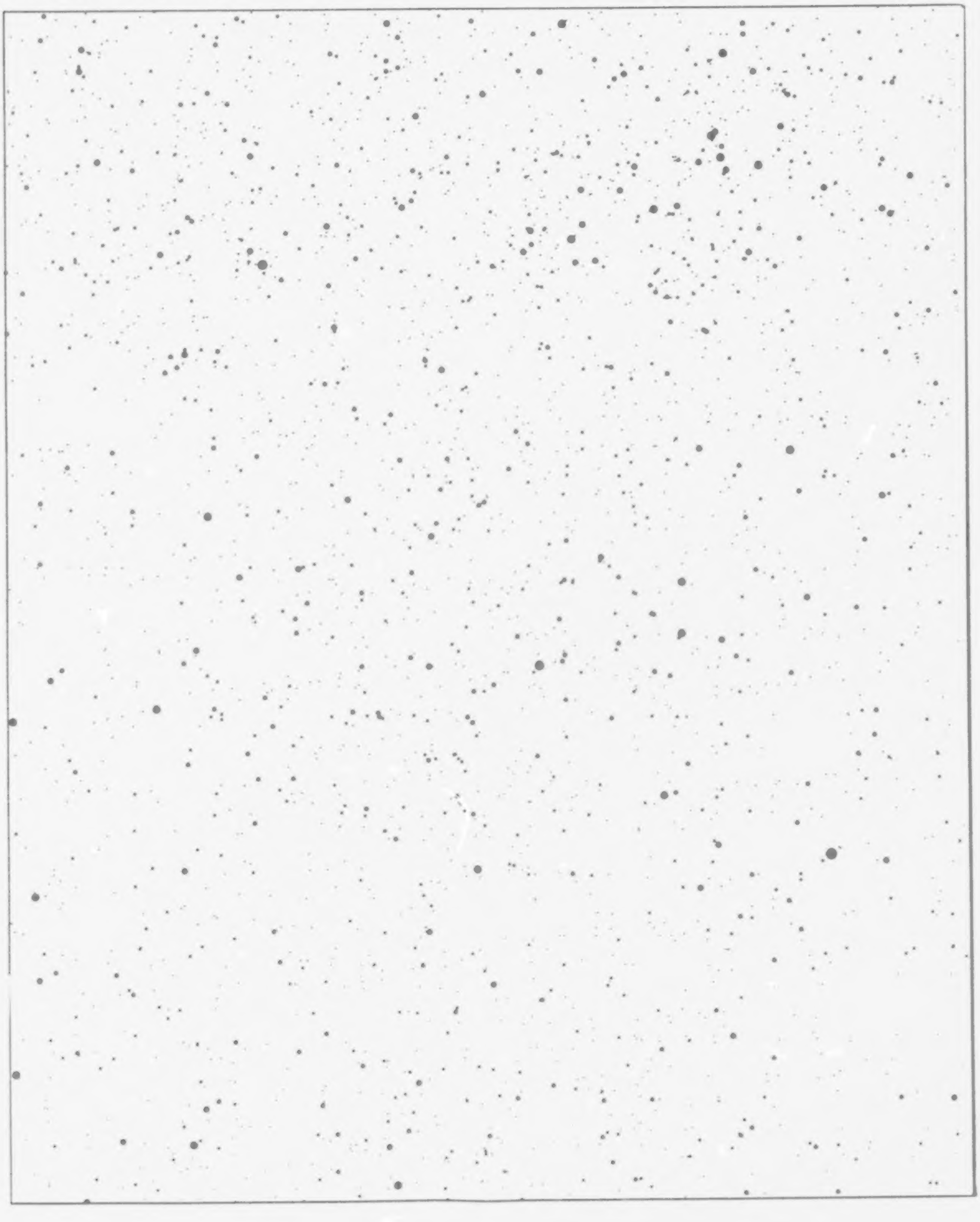
The Universe Today



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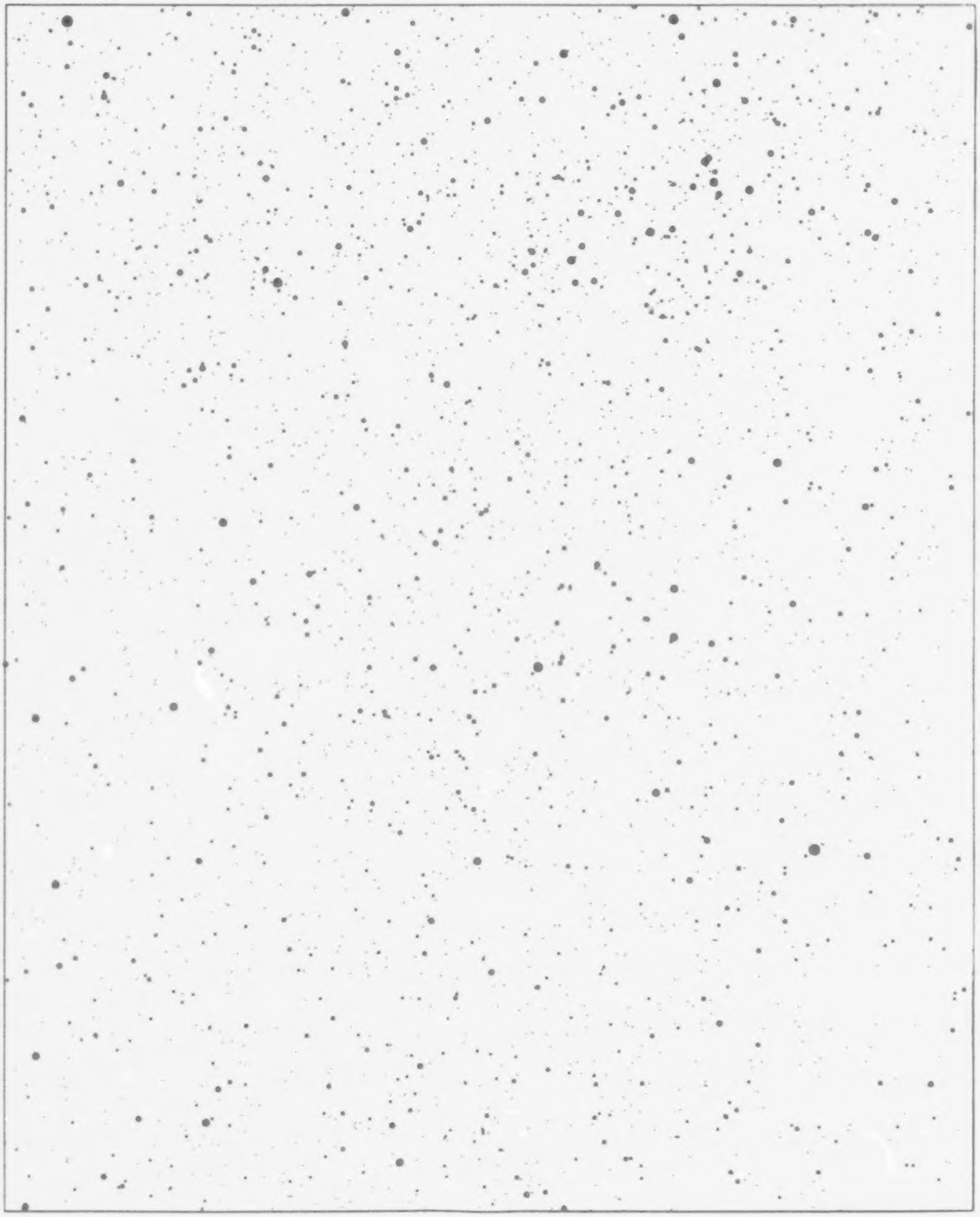
The Universe One Billion Years Ago



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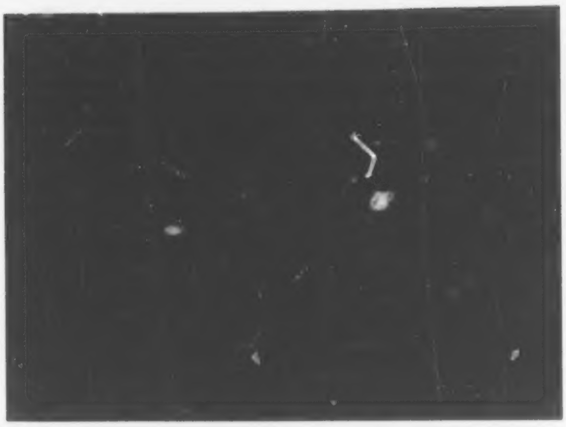


RESOURCES FOR EXPLORING GALAXIES

by Andrew Fraknoi
Astronomical Society of the Pacific
390 Ashton Avenue
San Francisco, CA 94112

Books and articles marked with a • are especially useful for those just becoming familiar with the subject.

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

- • Ferris, T. *The Red Limit,* 2nd ed. 1983, Morrow. An excellent history of how we learned about the large-scale structure of the universe.
- • Dressler, A. *Voyage to the Great Attractor.* 1994, A. Knopf. Very nicely written and personal book by a noted astronomer on how discoveries are made in the study of galaxies.
- Hodge, P. *Galaxies.* 1986, Harvard U. Press. Clear introduction to the field.
- Lemonick, M. *The Light at the Edge of the Universe.* 1993, Villard/Random House. The science editor of *Time* magazine summarizes current understanding of extragalactic astronomy.
- Parker, B. *Colliding Galaxies.* 1990, Plenum Press. Good primer of colliding, merging, or cannibal galaxies.
- Comins, N. & Marschall, L. "How Do Spiral Galaxies Spiral?" in *Astronomy,* Dec. 1987, p. 6.
- • Lake, G. "Understanding the Hubble Sequence [of Galaxies]" in *Sky & Telescope,* May 1992, p. 515. Good discussion of why there are different types of galaxies.
- Lake, G. "The Cosmology of the Local Group" in *Sky & Telescope,* Dec. 1992, p. 613. Introduction to the group of galaxies which we are part of.
- Hodge, P. "Our New Improved Cluster of Galaxies" in *Astronomy,* Feb. 1994, p. 26.
- • Trefil, J. "Galaxies" in *Smithsonian,* Jan. 1989, p. 36. Nice long review article.
- Keel, W. "Crashing Galaxies, Cosmic Fireworks" in *Sky & Telescope,* Jan. 1989, p. 18.
- Finkbeiner, A. "Active Galactic Nuclei" in *Sky & Telescope,* Aug. 1992, p. 138.
- Corwin, M. & Warchowiak, D. "Discovering the Expanding Universe" in *Astronomy,* Feb. 1985, p. 18.
- Geller, M. & Huchra, J. "Mapping the Universe" in *Sky & Telescope,* Aug. 1991, p. 134. On surveys that reveal large-scale filaments, voids, etc.
- Struble, M. & Rood, H. "Diversity Among Galaxy Clusters" in *Sky & Telescope,* Jan. 1988, p. 16.
- Ferris, T. "Where are We Going?" in *Sky & Telescope,* May 1987, p. 486. On all our different motions within the local supercluster of galaxies.

On the Milky Way Galaxy

- Davis, J. *Journey to the Center of the Galaxy.* 1991, Contemporary Books. A journalist reviews our current understanding.

- Henbest, N. & Couper, H. *The Guide to the Galaxy.* 1994, Cambridge U. Press. Beautiful, illustrated review.

Kaufmann, W. "Our Galaxy" in *Mercury,* May/June 1989, p. 79; Jul/Aug. 1989, p. 117.

van den Bergh, S. & Hesser, J. "How the Milky Way Formed" in *Scientific American,* Jan. 1993, p.72.

- Verschuur, G. "Journey Into the Galaxy" in *Astronomy,* Jan. 1993, p. 32. Excellent tour.

On Observing Galaxies with Small Telescopes

Eicher, D. *Galaxies and the Universe.* 1992, Kalmbach. An observing guide, with articles reprinted from *Astronomy* Magazine.

Clark, R. "A Visual Tour of M-31" in *Sky & Telescope,* Nov. 1993, p. 100. Observing our nearest major galaxy neighbor.

Goldstein, A. "Galaxy Hunting Around the Big Dipper" in *Astronomy,* Mar. 1989, p. 78.

Mood, J. "Eyeing the Local Group [of Galaxies]" in *Astronomy,* Nov. 1993, p. 94.

SELECTED READINGS FOR STUDENTS

Grades 4-6

Asimov, I. & Walz-Chojnacki, G. *Our Vast Home: The Milky Way and Other Galaxies.* 1995, Gareth Stevens.

Couper, H. & Henbest, N. *Galaxies and Quasars.* 1987, Franklin Watts.

Hughes, D. *Story of the Universe.* 1991, Troll Associates.

Simon, S. *Galaxies.* 1988, Mulberry Books.

Grades 7-9

Apfel, N. *Stars and Galaxies.* 1982, Franklin Watts. Slightly lower level than those below.

Gustafson, J. *Stars, Clusters, and Galaxies.* 1992, Julian Messner.

Darling, D. *Galaxies: Cities of Stars.* 1985, Dillon Press.

SELECTED AUDIOVISUAL MATERIALS

The Backbone of Night and *The Edge of Forever* (episodes of the *Cosmos* TV series by Carl Sagan from Turner Home Video or the Astronomical Society of the Pacific) Includes impressive discussions of the Milky Way and of galaxies and the expansion of the universe.

So Many Galaxies, So Little Time (1993, 40-min video from the Astronomical Society of the Pacific) Introduction to the people and work of Geller and Huchra's group, making large-scale surveys of the universe.

Splendors of the Universe (4 sets of 15 slides each from the Astronomical Society of the Pacific) Magnificent color images of nebulae and galaxies, taken by David Malin.

M. Geller & J. Huchra, Smithsonian Astrophysical Observatory

Large-scale structure of a slice of the universe

RESOURCES FOR EXPLORING THE BIG BANG AND THE EXPANSION OF THE UNIVERSE

by Andrew Fraknoi
Astronomical Society of the Pacific
390 Ashton Ave.
San Francisco, CA 94112

NOTE: Resources marked with a • are especially appropriate for those just beginning their exploration of this topic.

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

Barrow, J. *The Origin of the Universe.* 1994, Basic Books. A short recent primer.

Boslaugh, J. *Masters of Time: Cosmology at the End of Innocence.* 1992, Addison-Wesley. A journalist reports from the frontiers of cosmological research.

• Ferris, T. *Coming of Age in the Milky Way.* 1988, Morrow. Excellent history of cosmological ideas from the Greeks onward.

Ferris, T. *The Red Limit*, 2nd ed. 1983, Morrow. A well-written history of recent developments in our exploration of the large-scale properties of the universe.

• Gribbin, J. *In Search of the Big Bang.* 1986, Bantam. Excellent beginner's introduction to ideas in cosmology.

Lemonick, M. *The Light at the Edge of the Universe.* 1993, Villard/Random House. A journalist surveys particle physics and cosmology and profiles their practitioners.

Lightman, A. *Ancient Light.* 1991, Harvard U. Press. Nice concise introduction to our modern picture of the origin of the universe.

Lightman, A. & Brawer, R. *Origins: The Lives and Worlds of Modern Cosmologists.* 1990, Harvard U. Press. Interesting interviews with active researchers in this field.

• Overbye, D. *Lonely Hearts of the Cosmos.* 1991, Harper Collins. Wonderful introduction to the way cosmology is being done today, with a focus on the people involved, especially Allan Sandage.

Silk, J. *A Short History of the Universe.* 1994, Scientific American Library/W. H. Freeman. A slightly higher level introduction by a distinguished astronomer.

Smoot, G. & Davidson, K. *Wrinkles in Time.* 1993, Morrow. The full story of the COBE discoveries, by one of the team leaders and a science journalist.

• Trefil, J. *The Moment of Creation.* 1983, Macmillan. An eloquent introduction.

Albers, D. "The Meaning of Curved Space" in *Mercury*, Jul/Aug. 1975, p. 16.

Corwin, M. & Wachowiak, D. "Discovering the Expanding Universe" in *Astronomy*, Feb. 1985, p. 18.

Davies, P. "The First One Second of the Universe" in *Mercury*, May/June 1992, p. 82.

• Davies, P. "Everyone's Guide to Cosmology" in *Sky & Telescope*, March 1991, p. 250. Good introductory article.

Jayawardhana, R. "The Age Paradox" in *Astronomy*, June 1993, p. 39. On the conflict between the age of the universe from its expansion and from its oldest stars.

- Lemonick, M. "The Ultimate Quest" in *Time*, Apr. 16, 1990, p. 50. Cover story on the work in particle physics that is providing information for cosmology.

- Lemonick, M. & Nash, J. "Unraveling Universe" in *Time*, Mar. 6, 1995. Cover story on puzzling new evidence in cosmology from the Hubble Space Telescope and other instruments.

Osterbrock, D. "Edwin Hubble and the Expanding Universe" in *Scientific American*, July 1993, p. 84.

Parker, B. "The Discovery of the Expanding Universe" in *Sky & Telescope*, Sep. 1986, p. 227.

Peebles, J., et al. "The Evolution of the Universe" in *Scientific American*, Oct. 1994, p. 53.

Rothman, T. "This is the Way the World Ends" in *Discover*, July 1987, p. 82. On the future of the universe in the different models.

Scherrer, R. "From the Cradle of Creation" in *Astronomy*, Feb. 1988, p. 40. On the early universe and how we learn about it now.

- Talcott, R. "Everything You Wanted to Know about the Big Bang" in *Astronomy*, Jan. 1994, p. 30. Very basic questions and answers.

Talcott, R. "COBE's Big Bang" in *Astronomy*, Aug. 1992, p. 42. On the observation of statistical fluctuations in the CBR.

SELECTED READINGS FOR STUDENTS

Grades 4-6

Asimov, I. *How Did We Find Out about the Universe?* 1983, Walker & Co.

Asimov, I. *How Was the Universe Born?* 1989, Gareth Stevens.

Dickinson, T. "The Big Bang" in *Odyssey*, Dec. 1992, p. 4.

Hughes, D. *The Story of the Universe.* 1991, Troll Associates.

Opalko, J. "COBE Supports the Big Bang Theory" in *Odyssey*, Dec. 1992, p. 28.

Grades 7-9

Darling, D. *The Universe: Past, Present, and Future.* 1985, Dillon Press.

Gribbin, J. & M. *Time and Space.* 1994, Dorling Kindersley.

Simon, S. *Stephen Hawking: Unlocking the Universe.* 1991, Dillon Press.

SELECTED AUDIOVISUAL MATERIALS

Coming of Age in the Milky Way (audiotape from the book by Timothy Ferris; 2 hrs. 48 min., Dove Books on Tape) Includes a section on modern cosmology.

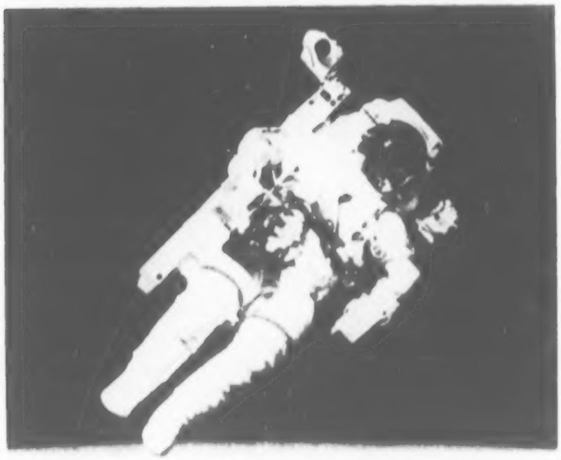
The Creation of the Universe (90 min video of the public television special, from PBS Video) Narrated by Timothy Ferris, this superb program is a wonderful introduction to modern cosmology.

The Edge of Forever (episode of the *Cosmos* TV series by Carl Sagan, from Turner Home Video or the Astronomical Society of the Pacific) Includes discussions of the Big Bang, the expanding universe, and various cosmological models.

Window to Creation (episode of *The Astronomers* TV series, 1991, from PBS Video) Focuses on the cosmic background radiation, and experiments to observe it.

I

SPACE EXPLORATION AND SETI

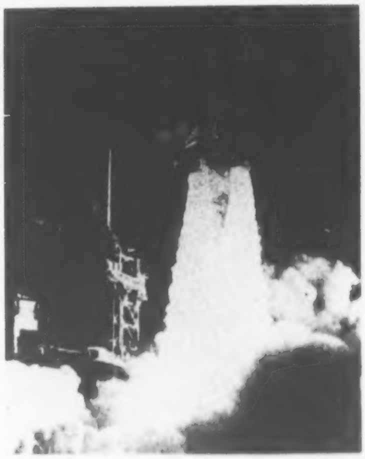


ACTIVITIES INCLUDED IN SPACE EXPLORATION AND SETI

ACTIVITY	ESTIMATED GRADE LEVEL											
Grades	1	2	3	4	5	6	7	8	9	10	11	12
I-1. Designing a Planetary Probe Students design a space probe to study specific planets.			□	■	■	■	■	■	■	□	□	□
I-2. Decoding an Extraterrestrial Message Students decode a simulated extraterrestrial message.					□	■	■	■	□	□		
I-3. Pack Up for a Trip to the Moon Students discuss and rank what they would take from a supplied list of items if they were stranded on the Moon.				□	□	■	■	■	■	□	□	□
I-4. Building a Lunar Settlement Students use their knowledge and imagination to build models of a settlement on the Moon out of commonly available materials.			■	■	■	■	■	■	■	□	□	□
I-5. Hello Out There: Message from Space Students consider how we might construct a message to send to beings elsewhere in the universe, and try to decode a simulated message received here on Earth from such beings.						□	■	■	■	□	□	□
I-6. Invent an Alien Students devise an alien creature suited to the conditions on a moon or planet and describe it to their classmates.			■	■	■	■	■	■	■	■	■	■

■ - Grade levels recommended by authors □ - Can be extended to these grade levels.

About the Activities:
Space Exploration and SETI



KEY IDEAS IN "SPACE EXPLORATION AND SETI"

- Ever since the telescope was invented and the idea that the Earth is a planet became widely accepted, people have wondered if life exists on other worlds.
- In recent decades new technologies have made the exploration of our neighboring planets a reality, and the transport of people and robot space probes has provided new opportunities for the search for life on other planets.
- Not only is the search for life beyond Earth highly motivating, it is also a truly interdisciplinary field.
- The *Benchmarks for Science Literacy* identifies several crucial concepts for science literacy (such as evolutionary biology, diversity of life on Earth, and the Copernican revolution) that are related to exploration of the solar system and the search for life on other worlds.

In the year 1609, Galileo was the first person to view the Moon with a telescope. It appeared so much like the surface of Earth, with mountains, valleys, and even dark areas that looked like "seas," that Galileo imagined people might live there. Learning about Galileo's discovery by letter, fellow astronomer Johannes Kepler (who was the first to work out the mathematics of elliptical planetary orbits) wrote one of the world's first science fiction stories about life on other worlds.

The century of Galileo and Kepler was also the time that people began to accept Copernicus's theory that Earth was one of several planets circling the Sun, and not a unique place at the center of the universe, created just for people. Ever since that time, people have wondered if life might exist on one of the other planets of our solar system; or perhaps in some other system of worlds, orbiting around a distant star.

In recent decades new technologies have made the exploration of our neighboring planets a reality, and the transport of people and robot space probes has provided new opportunities for the search for life. Apollo astronauts have walked on the Moon, searching for clues to its past. And the

Viking robot spacecraft, which landed on Mars in 1976, conducted experiments to reveal any possible life processes that might exist. Unfortunately, no life was found, and today most scientists believe that the chance for finding life elsewhere in the solar system is slim.

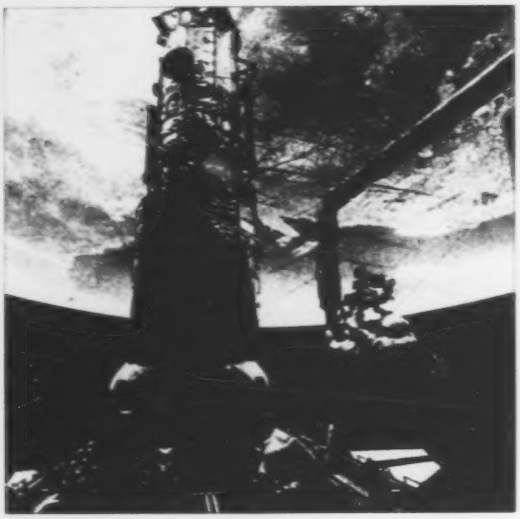
Still, the further exploration of our solar system and the search for life on planets that orbit other stars continue to be areas of active research, and provide some of the most exciting educational opportunities for students. Not only is the search for life beyond Earth highly motivating, it is also a truly interdisciplinary field. For example, consider just a few of the many questions that a unit in this area might address:

- What are some of the technical problems that must be solved to explore the solar system? (astronomy, technology and physics)
- What have we learned about the environments of our solar system's neighbors? (astronomy, geology, climatology)
- What does the adaptation of life to a wide variety of environments on Earth tell us about how life might adapt to conditions on other planets? (evolutionary biology, diversity of life)
- Do other stars have planets? (astronomy, physics)
- If there is life on another planet, how might we detect it? (biology, chemistry, scientific instruments)
- If there is intelligent life on other worlds, how might they communicate with us? (astronomy, technology, communication, information theory)
- What might a culture that evolved on another world be like? (evolutionary biology, anthropology, literature)

The *Benchmarks for Science Literacy* discusses a great many concepts that are related to exploration of the solar system and the search for life on other worlds. For example, "By 12th grade, students should know that: Life is adapted to conditions on the Earth, including the force of gravity that enables the planet to retain an adequate atmosphere, and an intensity of radiation from the Sun that allows water to cycle between liquid and vapor." (*Benchmarks*, page 70.) This concept can best be learned if students compare Earth with other planets, such as Mercury, where all liquid water has turned to vapor and escaped the planet long ago, and the outer planets, where any water must perpetually be frozen.

The *Benchmarks* (pages 239-241) also recommends that students learn about the story of the Copernican Revolution, including the contributions of Galileo and Kepler. A unit in which students explore the solar system or search for life on other worlds might well begin with this important historical background.

Several of the activities in this section are concerned with the exploration of the solar system by space probes and by actually traveling to other planets. Others are explicitly concerned with the possibility of life on other worlds, and the problems involved in communicating with intelligent beings that are likely to be very different from ourselves.



BACKGROUND: SPACE EXPLORATION

In the second half of the 20th century, we humans have taken our first tentative steps away from Mother Earth. Hundreds of satellites now orbit our Earth, providing a steady stream of information on weather, navigation, and communications back to the ground. Fourteen men have walked on the surface of our Moon. We have sent robot spacecraft to investigate all the planets of our solar system, except Pluto. Other unmanned craft have flown past comets and asteroids, sending back detailed pictures and information. Although the technology to accomplish these things has only existed for a few decades, many of the basic ideas of spaceflight and orbiting satellites are much older.

In 1686, the English physicist Isaac Newton published his now-famous book on gravity and its effects on the motions of objects. His work enabled scientists to, for the first time, understand how one object can stay in orbit around another. Imagine that you put a cannon on top of a very, very high mountain. If you fire it horizontally, the cannonball will fly through the air and then fall to the ground not far from the base of the mountain. If you use more gunpowder, the cannonball will travel faster, hitting the ground farther from the foot of the mountain than before. If you could use enough gunpowder, you could send the cannonball moving so fast that it would never strike the ground, circling the Earth to return to the mountain from which it was fired. The cannonball would be in orbit.

Newton figured out that the only force acting on the cannonball is gravity. Our planet's gravity pulls the cannonball toward the Earth's center, but, as it flies through the air, the Earth's surface curves away from the cannonball at the same rate at which it falls toward the center. In the same way, the Moon literally "falls" around the Earth, completing one circuit every month. Another way to think about it is to say that the cannonball wants to move in a straight line, but Earth's gravity pulls it away from its straight-line motion into a curve around the Earth.

The idea of putting cannonballs in orbit around the Earth has been around for centuries. In one of novelist Jules Verne's stories, an enemy army plans to bomb a city with a gigantic cannonball. However, they give the cannonball too much speed, and it passes harmlessly over the city and into a circular orbit around the Earth. The problem has always been figuring out how to provide a big enough push to achieve the speeds necessary for orbit, at least 18,000 miles per hour. The space age had to wait for the development of large rocket boosters.

On October 4, 1957, Sputnik I, the first artificial Earth satellite, was successfully launched by the then-Soviet Union. Sputnik, the Russian word for "satellite," weighed about four tons and orbited the Earth once every 96 minutes. It traveled in an oval-shaped orbit that ranged from 230 to 950 kilometers (140 to 590 miles) above the Earth's surface. This was low enough that friction with the tiny amounts of atmosphere present at those heights gradually caused Sputnik to slow down and lose energy. Ultimately, the Earth's first artificial satellite burned up as it entered denser, lower parts of the atmosphere three months after its launch.

Sputnik's launch sparked a "space race" between the Soviet Union and the United States, which culminated in the Apollo missions to land astronauts on the Moon and return them safely to Earth. Years of study by robot spacecraft from both countries that landed (and sometimes crash-landed) on the Moon's surface preceded the Apollo missions, as did manned missions in Earth orbit to practice the skills needed. Then, on July 20, 1969, Neil Armstrong became the first human being to set foot on another world, as he stepped out of his landing craft to explore the bleak lunar surface. The Apollo astronauts returned with hundreds of pounds of rocks and other material collected from the lunar surface, which have revealed a great deal of information about the Moon and its history.

Today, NASA's manned spaceflight program focuses on Earth orbit, with two-week-long missions in the Space Shuttle to conduct scientific experiments, and plans for longer stays aboard a yet-to-be-built space station. In the meantime, the Russian Mir space station has been staffed almost continuously since 1986, with some cosmonauts staying onboard for more than a year at a time. The "space race" competition of the past is giving way to a new era of cooperation between the two countries, as both struggle to contain the costs of space exploration.

Although manned spaceflight gets much of the media attention, both countries also have had thriving programs of unmanned exploration. Robot spacecraft have traveled to all the planets, except Pluto (and there are plans to visit it in the future). The two Voyager spacecraft flew past the giant planets of the outer solar system, and, for the first time, astronomers could study Jupiter, Saturn, Uranus and Neptune, their moons and rings "up close and personal." Magellan's radar "eyes" peered through the thick clouds of Venus, mapping the planet's surface in surprising detail. Two Viking spacecraft landed on Mars, and sampled the red planet's soil for signs of life (results of the experiments were inconclusive; some activity was seen, but it could be explained by ordinary, non-organic, chemical reactions).

Our exploration of the solar system continues today. The Galileo spacecraft, despite a stuck antenna that hampers communication, arrives at Jupiter in 1995 with a small probe that will be sent plummeting deep into Jupiter's gaseous atmosphere. Other missions are planned to revisit Saturn (Cassini), rendezvous with an asteroid (NEAR), and return to the red planet (Mars Pathfinder). Through our manned and unmanned space programs, we have been privileged to be among the first humans in history to explore the moons, planets, asteroids and comets with which we share our solar system. In our time, we have seen Newton's and Verne's dreams come true.

Courtesy Cornell University

Radio Telescope at Arecibo, Puerto Rico

BACKGROUND: THE SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE

Is anybody out there? That simple question has captivated scientists, philosophers, and science-fiction writers for centuries. Are we alone in the universe? Or do other planets support life? Many scientists today think that given the right conditions and enough time, life will develop. We know that organic molecules, carbon-based compounds that form the building blocks of life as we know it, are scattered abundantly throughout the Galaxy. In interstellar clouds and newly fallen meteorites, astronomers have found complex organic molecules, such as ethyl alcohol (the drinkable kind) and formaldehyde (embalming fluid). But a widespread abundance of these organic precursors does not, of course, guarantee that life is commonplace. For example, in our own solar system, life seems to have developed only on Earth.

Apparently, certain conditions must be met, such as the amount of warmth received from the parent star, in order for life to begin. We know that life evolved here on Earth, a product of volcanic gases, organic chemicals brought by impacting comets and meteorites, and naturally occurring chemical reactions. If there are planets orbiting other stars, as seems likely, perhaps conditions on some of them are suitable for life as we know it to develop.

Astronomers believe that the number of advanced civilizations in our Galaxy depends on several factors (first suggested in this form by Frank Drake): 1) the rate at which stars like the Sun form; 2) the fraction of those stars that have planets; 3) the number of planets, per solar system, that have an environment suitable for life; 4) the fraction of those habitable planets on which life actually exists; 5) the fraction of those life-forms that evolve into intelligent species; 6) the fraction of those species that develop adequate technology and then choose to send messages out into space; and 7) the lifetime of that technologically advanced civilization. The first three factors are essentially astronomical in nature, the next two are biological and the last two sociological; most are unknown. The most speculative is the last; we ourselves have only recently developed the technological capability to send and receive interstellar messages. When all these factors are multiplied together, estimates of the number of advanced civilizations range from one to millions, depending on how optimistic our judgments about each factor are. Our Galaxy may be teeming with life, or we may be the only ones; we just don't know. As is so often true in science, theory can only carry us so far; now what we need are some hard experimental data.

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Assuming there are other civilizations, there are really only two ways for us to find out about them—visit them in person or send messages back and forth. Visiting them is, at present, not a realistic option. The distances between stars are so great that the time required for interstellar trips with any realistic technology (Star Trek is fiction, after all) is prohibitively long, requiring many generations for the crew. Our fastest spacecraft so far, the Voyagers, would take about 80,000 years to get to the nearest star. And the energy requirements of fast trips are truly daunting. Bernard Oliver has calculated the energy cost of a single one-way trip to a star ten light years away (a close neighbor), assuming it would take 20 years and using a perfect spaceship (that is, one that doesn't waste any energy). His result: the trip would require about 500,000 years worth of the total energy consumption of the entire United States! It is unlikely that Congress will fund that kind of investment anytime soon.

However, it is entirely possible to communicate with other civilizations by using waves that naturally travel through space at the speed of light (186,000 miles per second, the fastest speed possible). Among the many different ways we might try to communicate, radio waves—especially those called microwaves—are the least expensive (in energy terms) and the most efficient at carrying messages. They easily pass through our planet's atmosphere and are less likely to be absorbed by the dust scattered among the stars; thus they can travel farther than other types of waves. And there is very little background interference for radio waves, either from man-made or astronomical sources.

It's important to remember that radio communication with another civilization does not necessarily mean two-way conversations. Depending on how far away the other civilization is, it could take tens, hundreds or even thousands of years for radio waves to make the round-trip between question and answer. But if there are communicative civilizations "out there," they may already be sending out messages for their own purposes or to inform others of their existence. These are the types of messages our search programs may find. If there are more advanced civilizations out there, sending out messages to "beginner civilizations" like ours might be the sort of interesting "science fair" project an alien high school class would undertake.

By the way, since the early part of this century, we ourselves have been unintentionally transmitting signals into space—radio, radar and television—creating a "bubble" of radio energy expanding outward from Earth at the speed of light. By the end of the twentieth century, this bubble will be over one hundred light years in diameter. Although the signal would be extremely weak at that distance, some truly advanced technological civilization within that radio sphere may know we are here.

Some popular accounts of this subject have joked that one reason extraterrestrials are not visiting us is that they have listened to our radio and television broadcasting and, so far, have seen no sign of intelligent life on Earth. To be precise, however, while our planet may appear brighter overall in radio waves than it would naturally as a result of these broadcasts, it is unlikely than any program content would be decipherable many light years away.

Astronomers have begun to search for such unintentional, as well as intentional, signals from other civilizations; the programs are collectively known as the Search for Extra-Terrestrial Intelligence, or SETI. So far, no SETI program has found any evidence of extraterrestrial intelligence, but that's not surprising since nearly all have been limited by inadequate technology and lack of funding and telescope time. The first search was conducted in 1960 when radio astronomer Frank Drake, turned the giant 85-foot radio antenna of the National Radio Astronomy Observatory in Green Bank, West Virginia toward two Sun-like stars, named Tau Ceti and Epsilon Eridani. Both stars are about eleven light years away from us, near enough that any signals should be easily detected. He observed the two stars intermittently from April through July, but no "intelligent" signals were detected. Drake's experiment did, however, inspire researchers around the world to search for "intelligent" signals from other stars.

Astronomers compare these searches to looking for a needle in a very large haystack. Among the problems inherent to the search is the question of which stars to study. The Milky Way Galaxy has an estimated 100 billion or more stars. But not every star is likely to have an Earth-like planet on it. Where should you point your radio telescope? And to what channels should you listen? Here on Earth, when you want your favorite radio station, you tune to the channel (or frequency) they have been assigned in the radio spectrum. For extraterrestrial messages, we have no idea what channel they might be using.

Even if we look at the right star in the right frequency-range, we still might not hear an extraterrestrial message if it is too faint for our receivers to hear. And if our receivers are good enough, how do we know we'll recognize an extraterrestrial signal and be able to decode it? It would be wonderful if all alien civilizations knew Morse code, for example, but that's not very likely. Astronomers working on the search for extraterrestrial intelligence (SETI) have generally had to guess at the answers to many of these questions, a process that can be compared to poking your hand into the haystack at random, hoping you've guessed right and will feel the elusive needle.

The most sophisticated SETI project to date, begun by NASA in 1992, searched for complex signals in more than ten million radio channels simultaneously. Originally conceived in two parts—a targeted search of 800 stars like the Sun with high sensitivity and a lower-sensitivity survey of the entire sky—the NASA project stopped in 1994 when its funding was cut by Congress. SETI researchers have managed to continue a scaled-down version of the project with private funding. So far, they have not reported any detections of intelligent signals, but it's very early in the search and our haystack is enormous.

In addition to listening for signals from others, we have also intentionally sent a few (mostly symbolic) messages of our own. In 1974, Frank Drake and his colleagues used the gigantic radio telescope at Arecibo, Puerto Rico to beam an elaborate coded message in the direction of a star cluster containing millions of stars called M13. The message contained information, coded in the binary notation of ones and zeros, about elements essential to life on Earth and our solar system. However, because of the cluster's great distance, it will take the message 25,000 years to get there. Its transmission primarily served as a reminder of the kind of information an interstellar message can contain.

We really don't know if there are a lot of technologically advanced civilizations out there or not. There might be thousands of them, or we might be the only one. Detecting evidence of even one other civilization would have profound repercussions for us. It would mean we're not the only spark of intelligence in the vastness of the universe. But we'll never know if they're there unless we search for them.

DESIGNING A PLANETARY PROBE

ACTIVITY I-1

GRADE LEVEL: 4-9

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What's This Activity About?

This activity is excellent for students who have just learned about the characteristics of planets, moons, or other celestial bodies, and now want to imagine actually exploring the atmosphere or surface. The process of selecting appropriate tools for the situation is one all scientists follow. This activity also encourages collaboration and compromise among group members.

What Will Students Do?

In groups, students choose a particular planet, and design a probe by selecting specific tools to be used on a scientific mission to the planet. Groups can create models or "blueprints" of their probe and explain their choices to the class.

Tips and Suggestions

- For earlier grades, you may need to specify the planets to explore, but give the students the ultimate authority to choose what they take and why. For more advanced grades, encourage them to decide what the purpose of their probe is to be before selecting the tools.
- A list of tools is provided, but teachers might want to bring in actual samples, and/or review the names and purposes of each tool. The list could easily be extended for later grades, and more complex issues including weight or size limitations, energy supplies, and even cost, can be incorporated.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Planetary characteristics	Using Instruments	Models and Simulations
Functions of a space probe	Predicting	Structure
The uses of particular tools	Imagining	Systems and Interactions
	Reasoning	
	Communicating	
	Exploring	

KEY QUESTION Would you send the same kind of space probe to different planets?

MATERIALS pencils, paper, copies of "Planetary Information Sheets" (optional), glue or paste, scissors

THE MODEL Divide your class into eight groups (nine groups if you wish to have students design a moon probe). Each group will be responsible for designing a manned or unmanned probe, especially designed for a particular planet.

OBSERVATION Your students can gain a fair amount of information on the planets by viewing the PULSAR slide show on the planets. Students should also be encouraged to do research in the library, or to use the "Planetary Information Sheets" for additional information on the planets.

SPECULATION Have each group speculate on the type of space probe and devices that would be most appropriate for their planet. Students should also be prepared to justify their decisions. For added realism, you might act as the Congress, and have each team submit a proposal with estimated costs and justifications for their space probes. You may also wish to impose certain restrictions on each group. For instance, you might allow each group to choose no more than 15 of the following items:

1. wide angle TV camera (for a clear view of a planet and its moons
2. seismograph (planetquake detector)
3. thermometer
4. microscope
5. biological experiment (to detect life)
6. radar (to examine surface below clouds)
7. soil analyzer
8. lightning rod
9. wind velocity detector
10. radio telescope ("sees" radio emissions)
11. robot
12. computer
13. astronaut
14. food
15. air
16. water
17. bathroom
18. living quarters

continued

19. entertainment
20. magnetic compass
21. telescope
22. solar panels (for electric power)
23. nuclear reactor (for electric power)
24. rocket fuel
25. attitude jets (small rockets for changing direction)
26. Geiger counter (for detecting radiation)
27. air conditioner
28. heater
29. heat shield
30. meteor shield (to protect ship from being punctured by small meteorites
31. spacesuit
32. radio transmitter and receiver (for communications with Earth)
33. landing gear (for landing on a hard surface)
34. parachutes
35. glider (for cruising through an atmosphere)
36. flood lights
37. gas analyzer
38. weapons
39. scientific experiment of students' choice
40. other item of students' choice

Encourage your students to consider factors such as the feasibility of sending an astronaut on the very long voyage to Pluto, etc.

EXPERIMENT After your students have decided on the items and design of their planetary probes, have each group make a blueprint or cross-section diagram of their probe. It is best to have each student draw several components of the probe, and then have each group cut and paste the whole thing together. An alternative is to have members of each group gather "found" objects in order to build a 3-dimensional model of their probe (fairly realistic space probes can be made with cardboard tubes, empty coffee cans, small boxes, aluminum foil, and paint). The "experimental" part of this activity is a "thought" experiment. A representative of each group should describe the conditions on their planet, and explain to the class why they designed their probe as they did. The class can then discuss the merits and shortcomings of each probe.

ADDITIONAL Exploring the Surface of Venus, Surviving on Another Planet, How High Can You Jump?

DECODING AN EXTRATERRESTRIAL MESSAGE

ACTIVITY I-2

GRADE LEVEL: 6-8

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What's This Activity About?

This exercise introduces how to analyze a message for signs of intelligent origins. Students learn that communication with forms of intelligence that do not "speak" any of our languages on Earth is likely to be difficult. Students mathematically examine a sample message. This can be a launching point for the study of computers, crypto-analysis, or digital communications.

What Will Students Do?

Students receive a simulated message of two "sounds,"and plot the message on a grid to determine its content. Students then devise similar messages for their classmates.

Tips and Suggestions

Follow this activity with "Hello Out There: Message from Space" found later in this section. These activities create a solid unit about the science of communications in space between humans and some extraterrestrial intelligence.

What Will Students Learn?

Concepts
- Extraterrestrial communication
- Binary codes

Inquiry Skills
- Inferring
- Organizing
- Recording

Big Ideas
- Simulations
- Interactions

Mission 10

Decoding an Extraterrestrial Message

Figuring Out a "Message From ET"

Overview

In Mission 9, the students determined the most practical method of communicating with a distant extraterrestrial civilization. In Mission 10, the students will learn to translate a radio signal into information that Earthlings can interpret.

What would an extraterrestrial message look like? How would we decode it? In Part One of this Mission, the students hear a sample message and discuss codes. In Part Two, they will have a chance to decode a complex "practice" extraterrestrial message made by a SETI scientist.

Concepts

- Extraterrestrials will not speak any known Earth language.
- A message from an extraterrestrial civilization may be difficult to interpret.
- The laws of mathematics and the laws of physics will be the same for us and for any extraterrestrial cultures.
- An extraterrestrial culture may use mathematical concepts such as prime numbers to transmit nonverbal ideas as a message.
- A message from an extraterrestrial civilization may appear in the form of a picture.

Skills

- Decoding messages.
- Pattern recognition.

Adapted from *The Rise of Intelligence and Culture*
SETI Institute, Teacher Ideas Press, Englewood, CO, 1(800)237-6124

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What You Need

PART ONE

For the Class:

- Overhead projector
- Tape recorder
- Blank tape
- Two different noise makers

For Each Student:

- Student Logbook
- Pen or pencil

PART TWO

For Each Student:

- Student Logbook
- Pen or pencil

Getting Ready

PART ONE

One or More Days Before Class:

1. ***Teacher's Note:*** *Before beginning this activity, make sure that the students know about the concept of prime numbers. If necessary, review or present this crucial concept.*

2. Using two different sounds (they don't have to be beep -click) tape record the following message:

beep, click, click, click, click, click, beep, beep, click, beep, beep, beep, click, beep, beep, click, beep, click, beep, click, beep, beep, click, beep, beep, beep, click, beep, beep, click, click, click, click, click, beep.

Make sure that the recording is slow enough to hear the two individual sounds. Any two forms of signal can communicate two symbol messages (dots - dashes, two tones, pulse - blank). Extraterrestrials will not know any terrestrial language, but we assume that they will know math.

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Just Before the Lesson:

1. Set up overhead projector.

2. Draw a 5 by 7 grid on the board or overhead projector.

PART TWO

One or More Days Before Class:

1. Make copies of the large message. Try to 'de-code' the seven page message yourself.

Classroom Action

PART ONE

1. **Mission Briefing.** Have students refer to their Mission Briefing in their Student Logbook while one student reads:

> "You will receive a practice extraterrestrial message that was actually invented by one of our scientists. When we find a message from an intelligent civilization, we will need to interpret it, so use this one to refine your skills."

2. **Discussion.** Read and discuss the "What Do You Think?" questions on the briefing page: What do you need to know about extraterrestrial civilizations to decode a message from one? Allow students a few minutes to record their answers in their Logbooks.

3. **Lecture.** Explain that currently SETI scientists are exploring radio frequencies for signs of intelligent life in the universe. They expect a signal of intelligent origin to have a pattern that could not be made by a naturally occurring object. They also hope that a signal would contain interesting and helpful information. But how do you translate a radio signal into information that Earthlings can interpret?

4. **Demonstration.** Announce that you have an example of a radio message. Request that they listen carefully for information. Play the beep - click tape. Ask if anyone got useful information from the message. *No, it's just a bunch of noises*. Explain that radio astronomers do not expect to be able to understand an extraterrestrial message right away. They assume that they will need to 'decode' it first.

Allow students a few minutes to try and detect a pattern in the sequence they just listened to. Let them try to find a

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sequence of English words, sequences of numbers, and so forth.

Have the students open up their Logbooks. Ask a student to read number one: "SETI radio astronomers expect to receive an extraterrestrial message in the form of a radio signal. It might sound like two different noises if you were to listen to it on a radio. Here's an example."

Explain that they just listened to the beep-click message written below the first statement. Ask the students: Is it any easier to get information out of the message when it is written down? *No, it's just a series of two words.* Emphasize that E.T.'s don't speak any terrestrial language.

Have another student read number two: "In the hopes that this message contains information, the receiving radio astronomer would count up the total number of sounds and attempt to organize them in some way. Notice that there are 35 bits of information. 35 is only divisible by 35 and 1 or 5 and 7. This suggests that the beeps and clicks can be organized on a grid that is either 5 by 7 or 7 by 5." Any two forms of signal can communicate, two symbol messages (dots - dashes, two tones, pulse - blank). Extraterrestrials will not know any terrestrial language, but we assume that they will know math.

Ask the students why a picture from an extraterrestrial culture would be more useful than their printed language? *Because we probably won't be able to read their language.*

Have a student read number three: "Work carefully to translate the beeps and clicks into a grid picture. For each beep leave one square blank, for each click fill in one square. Work horizontally, from left to right. Be accurate! One mistake and all the information will be incorrect (using a pencil is a good idea). "Ask a student to demonstrate how to properly fill in a grid using the 5 by 7 grid you drew on the board or overhead projector, as in Figure 10.1.

beep (leave blank), click (fill in), click (fill in), beep (leave blank) and so forth.

5. **Activity.** Make sure the students understand the assignment. Have them work in their Student Logbook books to complete filling in the grids in their activity book.

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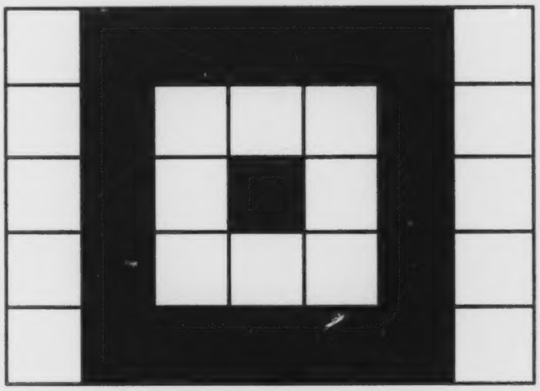

Fig. 10.1. Grid Showing Message.

6. **Discussion.** Which arrangement of beeps and clicks made the most sense? *The second one*. Why? *It formed a shape instead of scattered squares*. Tell the students that they will be seeing several messages intentionally sent by scientists from Earth to an unknown civilization. Ask the students to consider what method for sending the messages the scientists might have chosen and what information the messages might contain.

PART TWO

1. **Activity.** Announce that you have a message that might be what an extraterrestrial civilization would send. (This message was created by a SETI scientist.) The challenge to the students is to decode it to the best of their ability. Hand out the practice message to pairs or teams of students and give them 20-30 minutes to work.

Closure

1. **Activity.** Have students complete the questions in their Logbooks at the end of Mission 9.

Going Further

CLASS ACTIVITY: DESIGNER MESSAGES

Have students design a message for another class to decode. or divide the class into teams and have the teams make, trade, and decode messages.

Adapted from *The Rise of Intelligence and Culture*
SETI Institute, Teacher Ideas Press, Englewood, CO, 1(800)237-6124

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Mission 10

Decoding an Extraterrestrial Message

Dr. Roberta Vaile

Radio Astronomer on the SETI Academy Team

Mission Briefing: "You will receive a practice extraterrestrial message that was actually invented by one of our scientists. When we find a message from an intelligent civilization, we will need to interpret it, so use this one to refine your skills"

What do you think?

Before you begin this Mission, please answer the following question:

1. What do you need to know about extraterrestrial civilizations to decode a message from one?

2. What do you think such a message might say?

Adapted from *The Rise of Intelligence and Culture*
SETI Institute, Teacher Ideas Press, Englewood, CO, 1(800)237-6124

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Mission 10

Decoding an Extraterrestrial Message

Decoding a Radio Message

1. SETI radio astronomers expect to receive an extraterrestrial message in the form of a radio signal. It might sound like two different noises if you were to listen to it on a radio. Here's an example:

beep, click, click, click, click, click, beep, beep, click, beep, beep, beep, click, beep, beep, click, beep, click, beep, click, beep, beep, click, beep, beep, beep, click, beep, beep, click, click, click, click, click, beep.

2. In the hopes that this message contains information, the receiving radio astronomer would count up the total number of sounds and attempt to organize them in some way. Notice that there are 35 bits of information? 35 is only divisible by 35 and 1 or 5 and 7. This suggests that the beeps and clicks can be organized on a grid that is either 5 by 7 or 7 by 5.

3. Work carefully to translate the beeps and clicks into a grid picture. For each beep leave one square blank, for each click fill in one square. Work horizontally, from left to right. Be accurate! One mistake and all the information will be incorrect (using a pencil is a good idea).

Adapted from *The Rise of Intelligence and Culture*
SETI Institute, Teacher Ideas Press, Englewood, CO, 1(800)237-6124

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Name ____________________ Date ____________________

Mission 10

Decoding an Extraterrestrial Message

What do you think, now?

After you have completed this Mission, please answer the following question:

1. What do you need to know about extraterrestrial civilizations to decode a message from one?

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SETI Institute, Teacher Ideas Press, Englewood, CO, 1(800)237-6124

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PACK UP FOR A TRIP TO THE MOON

ACTIVITY I-3

GRADE LEVEL: 6-9+

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What's This Activity About?

Suppose you are stranded on the Moon—what would you need in order to survive? This is a fun, fast activity with lots of science underneath. It can be repeated for other planets or objects in the solar system to help students apply their knowledge of surface and atmospheric conditions.

What Will Students Do?

Students rank and discuss what they would take from a supplied list of items if they were stranded on the Moon. The list includes critical items (oxygen, water), useful ones (maps, rope), and some useless ones as well (matches, compass).

Tips and Suggestions

- Precede this activity with a discussion, and at least one video about the Moon, including footage of Apollo astronauts walking about on the Moon and riding in the Lunar Rover vehicle.
- Students can be tremendously creative with this activity. Consider linking it with a writing exercise or an art project. Depending on the list of items, the activity can also be used for earlier grades.

What Will Students Learn?

Concepts

- Surviving on the Moon
- Lunar surface conditions

Inquiry Skills

- Applying
- Evaluating
- Imagining

Big Ideas

- Simulations

Pack up for a trip to the Moon

To apply problem-solving skills to a consideration of living on the Moon.

The activity gives participants a list of items available to a fictional crew after a crash landing on the Moon and has them rank the items in importance.

Materials Needed

none

Strategies

Before beginning this activity, have your group make a list of everything that a four-person crew would need in order to live on the Moon for a two-week period. Later, either while you conduct the activity or afterwards, review the list. Does it account for some of the problem areas identified by the activity and the SPACE AGE program "To the Moon and Beyond"?

The problem-solving activity has been used by many different groups and is adapted from one on NASA SpaceLink, an electronic information system for educators. While no official solution to the problem exists, the chart presents rankings and rationales given by various "experts."

Individual student rankings can be compared with a group ranking or expert rankings. Error points can be calculated as the absolute difference between an individual and the group or between the group and expert rankings.

Extension

Have students pretend they are among the first people to live and work on the Moon. What rules will the Moon community follow? How and by whom will these be determined? How will they be enforced? Will a leader be selected? How? What environmental issues are likely to confront them? What occupations will be needed?

Invite students to produce the first newspaper or television news magazine show originating from the Moon. How will they describe daily life? What will their view be like? What discoveries will be made?

***Item** (Ranking)*	***Explanation***
matches (15)	No air on Moon so matches will not burn
food (4)	Efficient means of supplying energy requirements
rope (6)	Useful in scaling cliffs or use in case of emergency
parachute (8)	Possible use as sun shield
heater (13)	Not needed unless on dark side
pistol (11)	Possible means of self-propulsion
milk (12)	Bulkier duplication of energy source
oxygen (1)	The most pressing survival requirement
constellation map (3)	Primary means of navigation
raft (9)	Carbon dioxide bottle possible propulsion source
compass (14)	Useless; Moon has no global field
water (2)	Replacement of tremendous liquid loss on lighted side of Moon
flares (10)	Distress signal when rescue ship is sighted
first aid kit (7)	Needles for medicines and vitamins fit special aperture on suit
FM transceiver (5)	For communication with rescue ship on line of sight

Related Resources

Collins, M. *Liftoff, The Story of America's Adventure in Space.* New York: NASA/Grove Press, 1988.

The Eagle Has Landed: The Flight of Apollo 11. Video (28 minutes). 1969. Available from: NASA CORE, Lorain County Joint Vocational School, 15181 Route 58 South, Oberlin, OH 44074.

Lunar Phenomena. Slides on important aspects of the Moon. Available from: MMI Corporation, 2950 Wyman Parkway, P.O. Box 19907, Baltimore, MD 21211.

Program	***1***	***2***	***3***	***4***	***5***	***6***
				★		

Subject	***S***	***M***	***SS***	***T***	***LA***
	★		★	★	★

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Pack up for a trip to the Moon

You are a member of a crew on a trip to the Moon. Your spaceship crash lands on the Moon. A rescue craft is on its way to get you but it will be several days before it gets there and you will have to meet it at another landing site. The items listed at the right are the only things you have been able to save from your space ship. How important is each item to you in helping you to survive and reach the rendezvous point? Rank the items from 1-15 using 1 to mean most important and 15 to mean least important.

Discuss your reason for each ranking. For example, you might give the compass a relatively low ranking because it would be worthless for finding direction (the Moon has no global field). Its transparent cover could be used as a reflective signaling device, however.

Items

__ box of matches
__ food concentrate
__ 50 feet of nylon rope
__ parachute
__ portable heating unit
__ case of dehydrated milk
__ two 100 lb. tanks of oxygen
__ Moon constellation map
__ self-inflating life raft that uses a carbon dioxide canister
__ magnetic compass
__ 5 gallons of water
__ pistol with 6 bullets
__ self-igniting signal flares
__ first aid kit with hypodermic needles
__ solar-powered FM transceiver

➤

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- ★ ***What will be needed for long-term living on the Moon?***
- ★ ***What resources are already available on the Moon for a permanent Moon base?***

Before the 1960s, most people thought that humans could not live anywhere other than Earth. Since that time, more than 200 humans have lived in space for varying lengths of time, including 12 astronauts who lived on the Moon, some for as long as three days.

A permanent base on the Moon might be used for extracting materials from the Moon, conducting scientific research, or launching other space missions, such as a mission to Mars or an astronomical observatory.

The Moon is not a hospitable place. No food or water exists. Temperatures range from 120 degrees centigrade during the day to minus 180 degrees centigrade at night. Because the Moon has no atmosphere to absorb or deflect it, the Sun's radiation is dangerous. Long-term settlements on the Moon will require major life-support systems, new construction technologies, and many other scientific advances.

Sometimes low technology solutions will work as well as or better than high technology ones. Although a compass on the Moon is useless because of the lack of a global field, Apollo astronauts were able to use a gnomon (sun compass), which was used on Earth to find direction for hundreds of years before magnetism was discovered.

Current thoughts for a lunar base call for building living quarters under the Moon's surface to protect the crew from space radiation. Some building materials will be developed from resources available on the Moon. Lunar soil, for example, has been found to contain oxygen, silicon, glass, iron, aluminum, and magnesium. Robotic craft with a variety of capabilities and responsibilities are scheduled to build many of the structures. They will not need life support or as much protection from radiation. Finally, scientists are trying to develop a closed ecosystem that would generate food, water, and oxygen on the Moon.

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BUILDING A LUNAR SETTLEMENT

ACTIVITY I-4

GRADE LEVEL: 3-9

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What's This Activity About?

Students love to imagine what living and working would be like on another planet, and the path to answering their queries can involve some wonderful science. This activity capitalizes on our students' natural enthusiasm for unexplored areas in space, and the settlements they create can often be outstanding show-and-tell pieces.

What Will Students Do?

Students build a colony on the Moon (or on another planet or satellite) with materials provided to them, or brought from home. They describe the structures they built and give reasons based on planetary conditions.

Tips and Suggestions

- To strengthen the scientific thinking involved in this activity, ask students to provide a rational for each of the structures they build. Have students create a plan before they start building their models.
- For students in earlier grades, simply the existence of key buildings (food supplies, power, living quarters, etc.) may be sufficient. For older students, encourage creation of a settlement that truly takes into account the surface conditions, mission, and materials at hand.
- Tie this activity to written reports on the purpose of buildings, to creative writing assignments about life at the settlement, and to art with the creation of actual models. Supplement the activity with readings from science fiction stories, or a video of the Apollo astronauts on the moon.

What Will Students Learn?

Concepts	**Inquiry Skills**	**Big Ideas**
Requirements for living	Imagining	Models and Simulations
Simulations	Explaining	
Planetary/Lunar conditions	Communicating	

Building a Lunar Settlement

> *Here is a chance for you to use up some of those interesting scraps and snips of things that most people throw away, but could make perfect components for a model lunar settlement. In this activity, students first think of everything they would need to survive for years on a lunar settlement, and then design and build a model of such a settlement.*

Objectives

This activity can take on different meanings to different age students. For older students (grades 4-8), the question of what is necessary to survive in space can have special significance, since they soon may be candidates for space missions themselves. For younger students (grades 1-3), this activity is more of an open-ended creative process of building a home on the moon.

In this activity students will be able to:

1. Recognize (brainstorm) needs for human survival in space.
2. Design and build a model lunar settlement.
3. Communicate their design concepts and ideas with other students.

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Materials

For the class

☐ 1 or 2 boxes of raw material or "doo-dads" for settlement building. "Doo-dad" suggestions include: plastic or paper cups, small containers (such as empty yogurt or orange juice containers), packaging material (such as plastic casings on small items, clear "bubble-wrap" and styrofoam "peanuts" and other packing materials), egg cartons, styrofoam meat trays, cardboard tubes, corks, straws, film canisters, scrap wood, colored paper or poster board, assorted stickers—YOU NAME IT!

Note: To reduce clean-up time, limit the amount of styrofoam peanuts to about four cups.

☐ 1 or 2 skeins of color yarn or string
☐ 1 or 2 rolls of foil
☐ 1 roll of plastic wrap
☐ 1 box of toothpicks
☐ 1 box of straws
☐ 1 package of blank stick-on labels (masking tape can also be used)
☐ chalk and chalkboard, or overhead projector, unused transparency, and pens
☐ Optional: tools for use by teacher or under direct supervision, such as pliers for bending wire, utility knife for cutting tubes or styrofoam, hand saws, hammers, paper clamps, etc.

For each group of 4–5 students:

☐ 1 poster board, about 30 cm x 60 cm (about 1 ft. x 2 ft.) These serve as the base for each team's settlement (size can be adjusted to your preference)
☐ 1 or 2 glue bottles or glue sticks
☐ 1 or 2 scissors
☐ assorted color marking pens
☐ 1 roll of masking or cellophane tape

Before Class

1. Gather a few examples of the "doo-dads" listed above. Before the day of the activity, give the students a list of "doo-dads" so that they can start collecting for their projects. To give them an idea of what may be useful, show them the materials you have collected. Encourage the students to save any small objects that might turn into "space material" with a little imagination. Have them bring in their supplies from home.

2. Cut the poster board into approximately 30 x 60 cm (1 x 2 feet) rectangles to serve as bases for each team's settlement.

On the Day of the Class:

1. For quick distribution, assemble each group's supplies (glue, scissors, pens, and tape) on a tray or in a container.

2. Place the building materials in an accessible location. Students need to be able to retrieve material easily. Keep the tools such as pliers in a place that you can monitor. You could also wear a "tool belt" or carry a toolbox so you can go from group to group with all the special tools needed to assist students.

3. Arrange desks or tables and chairs so groups of 4-5 students can work together building a settlement for one of Jupiter's moons.

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In Class

Part 1: Planning a Moon Settlement

Imagine that you are to be among the first people to create a community on the Moon or on a moon of Jupiter or Saturn. It would take a spacecraft about **two or three YEARS** to transport people to or from the Jupiter system. You would need to establish settlements on the moons so you could live there for long periods of time. You will be working in teams to design and build a model of a settlement on a moon somewhere in our solar system.

In preparation for this mission, you first need to think about what conditions you will face. Imagine being on one of Jupiter's moons. ***How would things be different there?***

Take several answers and encourage the students to keep in mind such things as:

- Low gravity (1/3rd to 1/6th the gravity of Earth)
- Bitter cold temperatures: –100°C to –200°C (–148 F to –328 F) except on parts of Io
- Exposure to cosmic rays and radiation. (There is intense radiation on Io, Europa, and Ganymede, because of the interactions of Jupiter's gargantuan magnetic field with the solar wind. Only Callisto lies outside Jupiter's "magnetosphere" and so has less radiation.)
- No liquid water (except maybe on Europa)
- No air
- Little sunlight (1/25th as much as on Earth).

Think of essential items you would need to have with you on a moon settlement. Remember, you must be able to live for a few years there without returning to Earth.

Have the class brainstorm and list their ideas on the chalkboard or use an overhead projector. Among items that have been considered essential in actual planning of similar projects are such things as: living quarters, a greenhouse, solar panels/generators, storage facilities, a launch and landing pad, etc.

Divide the class into teams of 4–5 students who work well together. Arrange seating so they can share materials and work together on the model.

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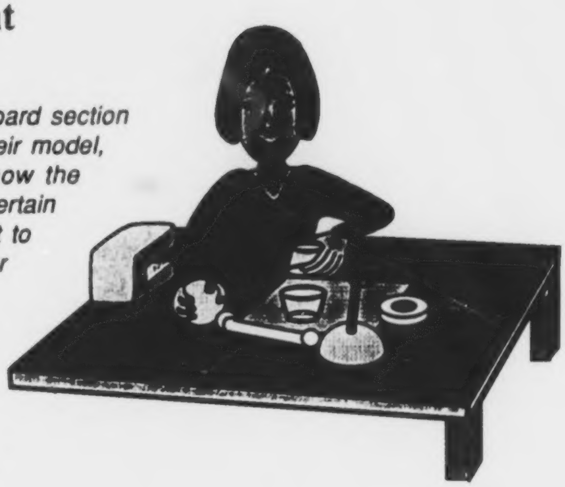
Part 2: Building the Settlement



Here are your raw materials.

Show the class a sample posterboard section and explain that they will be building their model, using a board like this as a base. Show the various raw materials they can use. If certain items are in short supply, you may want to set limits. (e.g. "Only one plastic tube per group, please!") Suggest ways for teams to be reasonable and cooperative in gathering and sharing materials.

After you have been working for a while, you will be given labels and asked to identify and label all the parts and structures you've developed. Your settlement should have all the essential requirements that we listed on the chalkboard.

Distribute group supplies and give a posterboard to each group. Let the teams get the "raw materials," and begin planning and building. Circulate and help as needed. Ask questions and encourage the students to use their imaginations.

When the settlements are well underway, bring around blank labels and have the students label each part of their settlement (launch pad, greenhouse, and so on).

Leave enough time at the end of class for clean up. If the students have not completed their models and you are planning more class time for them to work, encourage them to collect additional materials at home. Have them bring in these materials to incorporate into their settlements.

Part 3: Discussing Lunar Settlements

Now it's time to give the class a "tour" of your facility. Imagine that you are conducting tours for visiting dignitaries! I know you have put a lot of creative energy into your model settlements, and look forward to displaying and explaining your inventions and ingenuity.

Plan sufficient time for them to do this. They could present a "tour of the facilities." The presentations could all be made during one class period, or spread out over two or three days. Allow a few minutes for the other students to ask questions of each team. You may want to help guide and focus some discussion, with questions, such as:

- ***How does your settlement take into account the items on the requirement list?***
- ***What do you think it would it be like to live in this settlement?***
- ***What would you do for fun in your settlement?***
- ***What do you think the food would be like?***
- ***Would you really want to go on a mission like this?***

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Going Further

1. Have the students write a story about daily life in their settlement. They may want to write a special report on an exploration to some of the unusual features of their world, or describe some of their experiments. Or, they may want to write a "letter home," describing, for example, what it is like to look up in the sky and see Jupiter instead of Earth's Moon.

2. An option is to have each student build their own moon settlement. For this, you can supply each student with a baseboard of posterboard, or simply them them do it completely from scratch on their own as an extended home project. A variation on this idea is for the students to build free-floating space communities designed not for a moon's surface but to travel through space or orbit a planet on its own. In such communities, there is a technical challenge of dealing with a weightless environment. Most designs have the whole structure spinning to create artificial gravity in a direction outwards from the center.

3. Ask students to respond to the concern, raised by some people, that perhaps people should not establish settlements on other worlds. Some might say, for example, that these worlds should be left alone, so as not to be polluted or changed by human exploitation of natural resources, or by competition by governments and businesses to control specific areas or establish settlements. Do your students agree or disagree? How would they feel if missions were limited to exploration? How about setting up mines and factories on other worlds?

4. Several videos about the Voyager missions are available from NASA. Videos can be ordered from your nearest local NASA Teacher Resource Center. The Jet Propulsion Laboratory Teacher Resource Center specializes in inquiries related to space and planetary exploration, and other JPL activities. That address is listed below. Other NASA Centers are listed in PASS Volume 3, under "Organizations."

Jet Propulsion Laboratory
Teacher Resource Center
JPL Educational Outreach
Mail Stop CS-530
Pasadena, CA 91109
Phone: (818) 354-6916

5. There are many great stories related to space settlement. Here are some:

2010: Odyssey Two by Arthur C. Clarke
Ballantine Books, New York. 1982
Grades: 10–Adult

This complex, mysterious, and thought-provoking sequel to Clarke's *2001: A Space Odyssey* had the benefit of being written subsequent to the Voyager mission. Chapter 13 specifically, "The Worlds of Galileo," focuses on the four main moons of Jupiter, although there are fascinating observations, accurate scientific information, and lots of interesting speculation about Jupiter and its moons throughout the book.

Against Infinity by Gregory Benford
Simon and Shuster, New York. 1983
Grades 10–Adult

This science fiction novel is an account of human settlement on Jupiter's largest moon, Ganymede. The story takes place several hundred years into the colonization process, and begins from the perspective of a 13-year-old boy whose father is one of the leaders of the settlement. Advanced students may want to read this novel to gather ideas about constructing biospheres, melting ice, obtaining minerals, and other ways humans might possibly survive on the moons of Jupiter.

Jupiter Project by Gregory Benford
Bantam Books, New York. 1990
Grades 7–10

A teenager lives with his family as part of a large scientific laboratory that orbits Jupiter, but he is ordered to return home. He has one chance to stay; if he can make an important discovery.. There is a nice mix of physics and astronomy with teen-age rebellion and growing maturity, some love interest, and an exciting plot. The descriptions in Chapters 6, 7, and 8, which are part of an account of an expedition to Ganymede, could be compared by students to the information they observe and learn about this mammoth moon.

The Planets edited by Byron Preiss
Bantam Books, New York. 1985
Grades: 8–Adult

This extremely rich, high-quality anthology pairs a non-fiction essay with a fictional work about the earth, moon, each of the planets, and asteroids and comets. Introductory essays are by Isaac Asimov, Arthur C. Clarke and others. The material is dazzlingly illustrated with color photographs from the archives of NASA and the Jet Propulsion Laboratory, and paintings by astronomical artists such as the movie production designers of *2001* and *Star Wars*. "The Future of the Jovian System" by Gregory Benford (about colonization and development of Jupiter's moon Ganymede) is a perfect match to the moon settlement activity. However, since the vocabulary is sophisticated it may be more suitable for high-level readers.

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HELLO OUT THERE: MESSAGE FROM SPACE

ACTIVITY I-5

GRADE LEVEL: 7-9+

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What's This Activity About?

If we did receive a message from an extraterrestrial intelligence, what might it say? How would it appear? What would we say to aliens possibly "listening in" to our electromagnetic signals? This activity has sparked wonderful discussion and thought in the ASP's national workshops, and in classrooms across the country. The activity encourages students to apply what they know about our solar system and human exploration to an alien system.

What Will Students Do?

Starting first with the message attached to the Pioneer 10 and 11 spacecraft, students explore what might be put into a message to a presumed intelligent being who does not understand our language, symbols, culture, or even how we exist. From this analysis, they decode a simulated message from space.

Tips and Suggestions

- The simulated message from the extraterrestrial species actually incorporates a possible time line for their exploration of their solar system.
- Before tackling this activity, students should have a good foundation in what our solar system looks like. They will need to know the shape and dimensions of the Milky Way galaxy in order to decode the last part of the message.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Scale and structure of the solar system	Observing Systematically	Patterns of Change
Evolution of intelligence	Explaining	Models and Simulations
Time scales for exploration	Inferring	
	Reasoning	
	Describing	

HELLO OUT THERE: MESSAGE FROM SPACE

Astronomers and others have long been fascinated with the possibility of life existing in other parts of the universe. In this activity, students examine various attempts to communicate our existence to other intelligent life forms in our galaxy, and then analyze and interpret a simulated radio wave message received from a civilization orbiting a star many light years away.

CONCEPT

Communication using an unfamiliar language is a difficult process and may be based upon observation and inferences.

OBJECTIVES

Students will:

- use skills of observation and inference to interpret an unfamiliar communication system.
- understand how humans are attempting to communicate with other intelligent beings outside our solar system.
- use problem solving to interpret messages sent into space, and decode a simulated message from an intelligent civilization outside our solar system.
- develop a return message conveying important information about our civilization, and conceive a mechanism for sending a return message.

MATERIALS

Message from Space Illustrations (four pages of illustrations for simulated message)
Pioneer 10 and *Pioneer 11* Plaque Illustration
Arecibo Radio Message Illustration
envelope

PROCEDURE

Advanced Preparation:
This activity takes several days. Plan an adequate amount of class time. Make copies of the Message From Space Illustrations, the Pioneer *Plaque Illustration, and the Arecibo Radio Message Illustration. You may wish to create overhead transparencies of these illustrations. Fold and put one copy of the alien message from space in an envelope addressed from the imaginary Academy of Galactic Communications Research to use on Day 3.*
If possible, find a copy of Charles Osgood's poem, "Sounds of the Earth," from Nothing Could Be Finer Than a Crisis That Is Minor in the Morning, *Holt, Rinehart, Winston, 1979, pp. 186-188. It provides a humorous perspective about our attempt to communicate with distant worlds.*

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DAY 1

1. Begin a discussion about the possibility of life existing in other parts of the universe.

2. Divide students into groups of three or four. Give each group a copy of the *Pioneer 10* and *Pioneer 11* Plaque Illustration. Each group should examine the plaque, making a list of what they think humans were trying to communicate with the images on the plaque. Students should not be concerned with being right or wrong, but should work at making their best inferences based on their collective experiences and knowledge. This is similar to the process a distant life form would have to use if it discovers the plaque.

3. Have each group share its ideas with the rest of the class. Conduct a general discussion to synthesize the various ideas.

4. Follow the students' discussion with a description of what the plaque authors intended to communicate. This is a good time to emphasize how difficult it is to convey information when one doesn't know who will be receiving it.

5. Distribute copies of the Arecibo Radio Message Illustration that humans have sent into space. Allow students until the next class session to analyze the message on their own and come up with their best interpretation of it. Encourage them to get suggestions from family members.

DAY 2

1. Have students again work in their groups to analyze the Arecibo Radio Message Illustration and to share individual ideas. Each group should then prepare an oral presentation of its collective interpretation of this illustration.

2. Share each group's ideas with the rest of the class and then have a general discussion to synthesize the various ideas.

3. At the conclusion of the discussion, share with students the message the authors were trying to convey.

4. Have students work in their groups to devise a new message that conveys important characteristics of their culture. This could be a radio message like the Arecibo message, a physical message like the *Pioneer* plaque, or a time capsule aboard a spacecraft. Students should have as many options as possible. Allow the remainder of the class period to work on this project.

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DAY 3

Teacher's Note: Some acting skills should be used to allow students to believe in the possibility of the simulated message used in this activity. You should not give them any reason to believe otherwise. Your goal should be to treat this as a real science problem and to encourage students to use their best problem solving skills.

1. Before the groups have the opportunity to continue planning their new messages, tell the class that you have been asked by the Academy of Galactic Communications Research to analyze a radio message just received from what is thought to be a distant intelligent civilization. Indicate that you think the students would like to attempt interpreting it. You will convey whatever they discover to the Academy of Galactic Communications Research staff.

2. Explain that the message is similar to the one humans sent from the Arecibo radio telescope. The only thing known is that the message came from the direction indicated on the top of the message. This gives the exact direction the telescope was pointing, in a way similar to how we can locate an exact position on the earth using longitude and latitude.

3. Distribute copies of the message from space to each work group. Have them work together to decode it.
   Teacher's Note: It is important to emphasize throughout this activity that no one knows what information the message contains. This allows you to deflect all requests to be told what it says, which is in keeping with how science actually operates. A possible explanation has been included to give you an idea of the range of interpretation.

4. Allow time for analyzing the message. This activity works best if the groups have about 30 minutes one day to work on the message, and then a one- or two-day break before finishing their analysis.

DAY 4

(This may actually be two or three days after the last session.)

1. Have students return to their groups. During this session they are to finish analyzing the message from space and prepare a class presentation of their interpretation.
   Teacher's Note: Although students will continue to ask for the right answer and want to know if it is an authentic message, do not yet reveal the simulated nature of the message.

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2. Conduct a sharing session to reveal the interpretation ideas developed by each group. Discuss the various ideas. Tell the students that they have done the best job possible deciphering the message, and that you will convey the results to the Academy of Galactic Communications Research staff.

   Teacher's Note: After you have completed all related activities, you can inform the students that you learned the message was a prank being played by the Academy of Galactic Communications Research staff.

3. Conclude the session by having students complete the new message they would send into space. A return message to the extraterrestrials who sent the simulated radio message may be a new possibility. Important questions students should consider as they prepare the message are:
   - What are the important aspects of our culture that should be conveyed?
   - What are the advantages and disadvantages of different means of communication (e.g., low cost and speed of radio message versus greater variety and more concrete nature of time capsule aboard a spacecraft)?
   - How can return messages build on information the two civilizations have in common, based on the message sent to us?

4. Have each group share their return message with the rest of the class.

DAY 5

1. Begin with a class discussion on what students have learned from the previous activities about communication with beings from another part of the universe.

2. Share Charles Osgood's poem, "Sounds of the Earth." It emphasizes the challenge of deciding how to send information to a culture that we know nothing about—if it exists in the first place. What specific references to the challenge of long-distance communication with intelligent life in a faraway place are made in the poem?

GOING FURTHER

Do research to discover the information astronomers included on a record album sent aboard the *Voyager* spacecraft.

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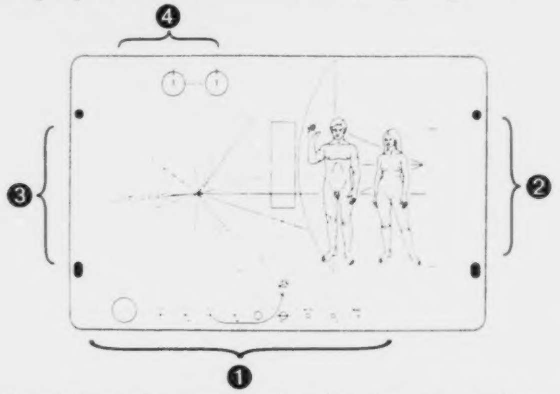
BACKGROUND INFORMATION

PIONEER PLAQUE

Pioneer 10 and *Pioneer 11* were launched in the early 1970s to examine the planet Jupiter in the mid-1970s. After flying past Jupiter, these spacecraft continued to travel to the outer reaches of space. Each spacecraft carries an identical 9-inch by 6-inch plaque that contains a message for a space travelling civilization that might discover the spacecraft as it traverses deep space. (Although not a part of its mission, it would take 100,000 years for *Pioneer* to travel to the nearest star, Alpha Centauri. The *Pioneer* spacecraft are not traveling in that direction.)

Key elements on the plaques are shown in the following diagram.



1) Schematic drawing of our solar system, showing the spacecraft coming from the third planet and flying by Jupiter and Saturn. Relative distances to the planets are given in binary notation next to each planet.

2) Male and female humans shown against silhouette of the *Pioneer* spacecraft. Humans are shown in proper relative size to the spacecraft. Hand gesture of the male is meant to be symbol of peace.

3) Position of our sun relative to 14 pulsars and the center of our galaxy. The sun is at the center of the lines, with the length of each line being proportional to the distance from the sun. The lines also represent the approximate direction of each pulsar from our sun. How often the pulsars pulse on and off is given in binary notation along the line pointing to each pulsar's location.

4) Schematic view of a hydrogen molecule, which is the most abundant substance in the universe. The period of pulsars is given in units based on the frequency of radio waves emitted by hydrogen.

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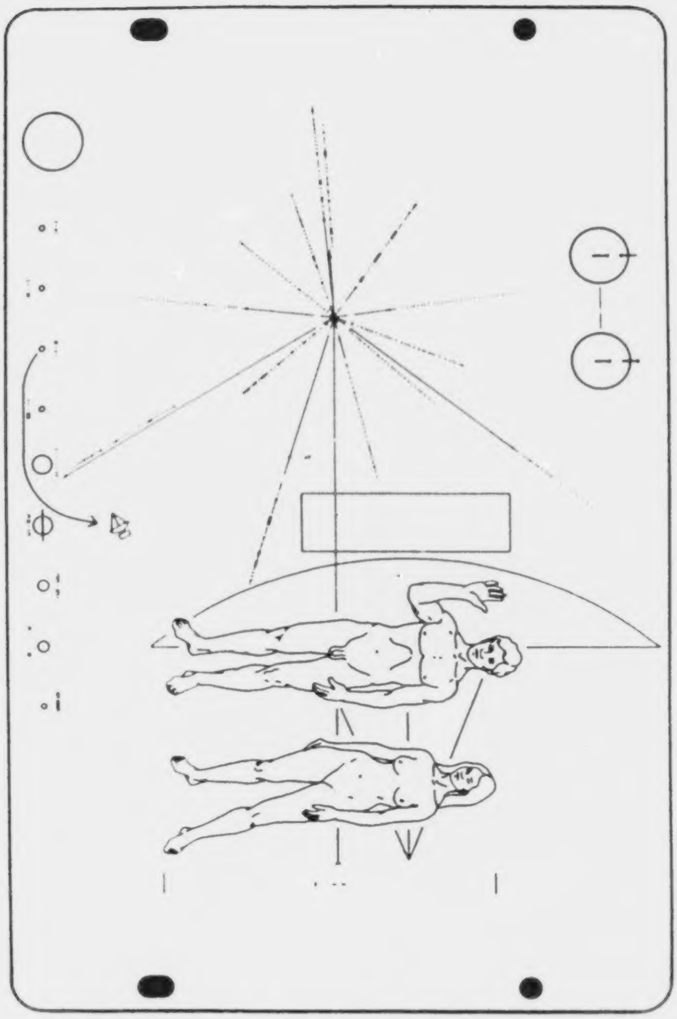
PIONEER 10 AND PIONEER 11 PLAQUE ILLUSTRATION



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BACKGROUND INFORMATION

ARECIBO RADIO MESSAGE

In 1974, a radio message was transmitted from the Arecibo telescope in Puerto Rico. It was sent in the direction of a cluster of stars 25,000 light years away. The message contained 1,679 bits of information, which can be thought of as a continuous string of X's and blanks—just like in the simulated message used in Day 3. Since 1,679 is the product of two prime numbers (73 and 23), it is hoped that the civilization receiving the message will realize that the string of information bits should arranged in a 73 x 23 array to produce the picture shown below. This illustration is a graphic representation of the radio message.

Key components of the message are:

1) The numerals 0 through 9 using a binary counting system.

2) The atomic numbers of the elements hydrogen, carbon, nitrogen, oxygen, and phosphorus, of which humans are made.

3) The nucleotides and sugar-phosphates of DNA, given in terms of elements shown in Component 2.

4) The number of nucleotides in the genes of the human shown in Component 5.

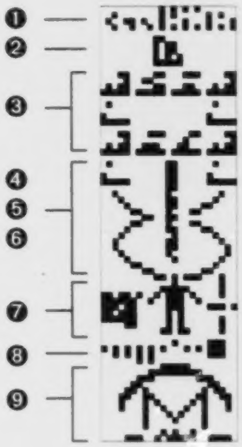
5) A schematic drawing of humans.

6) The height of the humans given in units of the wavelength of the radio waves used to transmit the message.

7) The human population of Earth in 1974.

8) A schematic drawing of the solar system, with the third planet being of special interest because it is out of line.

9) The radio telescope sending the message, with its size given between the horizontal lines at the bottom.



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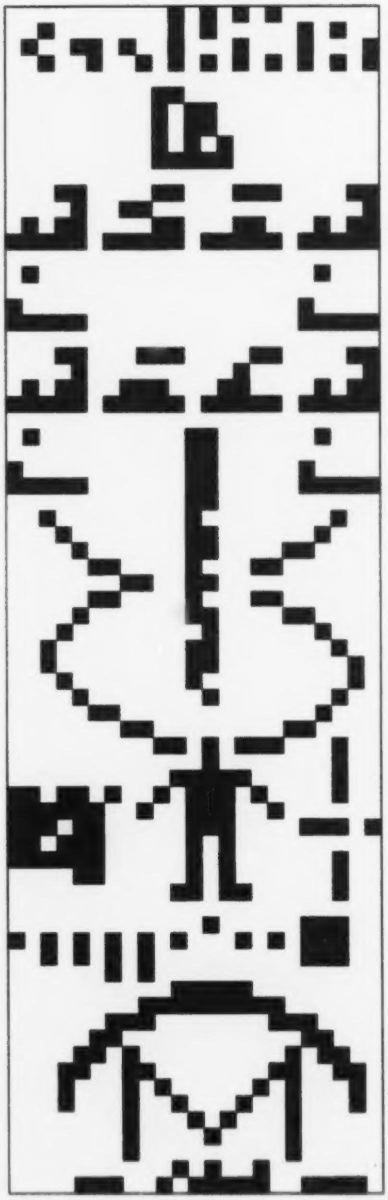
ARECIBO RADIO MESSAGE



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BACKGROUND INFORMATION

SIMULATED MESSAGE FROM SPACE

The following information is contained in the simulated message. Please remember that this activity works best if you do not reveal this information to the students until after their discussion of their interpretations.

1) The numerals 0 through 9.

2) A schematic drawing showing the formation of the distant civilization's planetary system, with the time zero shown at bottom. Planets are diffuse, indicating that they are still forming.

3) A schematic drawing showing that the planets have fully formed after a period of time. This is indicated by the information at the lower left side of the illustration. The numeral symbols translate to 1,000,000,000 (one billion) time units. The unit of time is unknown; it could be years, minutes, decades, seconds, or "blorks."

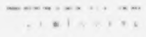
4) A schematic drawing showing that life has formed on the fourth planet from the central star. The time period is 4,000,000,000 time units from the very first illustration of the simulated message.

5) A schematic drawing showing that the three inner planets were colonized. Some students interpret this to mean that the civilizations on the other three planets destroy the fourth planet. Either interpretation is reasonable, although the fact that the three inner planets shown in Section 6 have formed into triangles probably gives the colonization interpretation the greatest weight. A period of 4,001,000,000 time units has passed since the beginning.

6) A schematic drawing showing that the fourth planet explodes 4,001,001,000 time units from the beginning.

7) A schematic drawing showing the present situation, with life on the three inner planets. The fourth planet is gone. A period of 4,001,001,153 time units has passed since the beginning.

8) Schematic drawing of our solar system. Note that the relative sizes of the planets are shown correctly, and that Saturn has rings. The numbering system of 0 through 9 is shown below the planets.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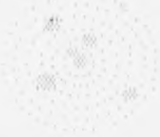
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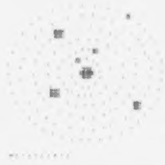
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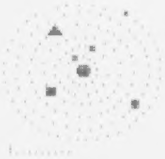
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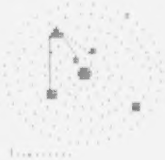
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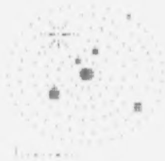
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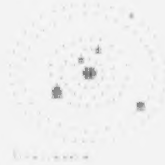
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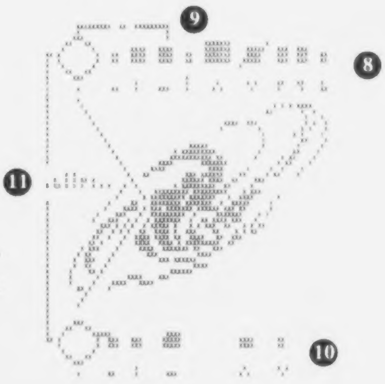
9) A line from our sun to the earth, with number 1 at the center of the line, shows that the distant civilization is using this distance to define both distance and time. The distance is 93 million miles, and the time for light to travel this distance is approximately eight minutes. This information can be used to provide units for the times expressed in previous sections, and to get the distance to the planetary system shown in Section 11.

10) A schematic drawing of the distant civilization's planetary system. The numbering system is repeated under each planet. Note that the fourth planet is missing. The short line between the star and the first planet indicates that the message is coming from that planet.

11) A schematic drawing of the Milky Way Galaxy, with lines showing the relative position of the two planetary systems. The number 19,447,200 appearing in the middle of the vertical line represents the distance, in astronomical units, between the two planetary systems. This equals almost 2 million billion miles (2,000,000,000,000,000), or 340 light years. (One astronomical unit is the distance from earth to the sun, 93 million miles.)



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A simulated Message from Space
from Pacific Science Center
Astronomy Education Curriculum Project
Funded in part by the
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NASA Space Grant Program

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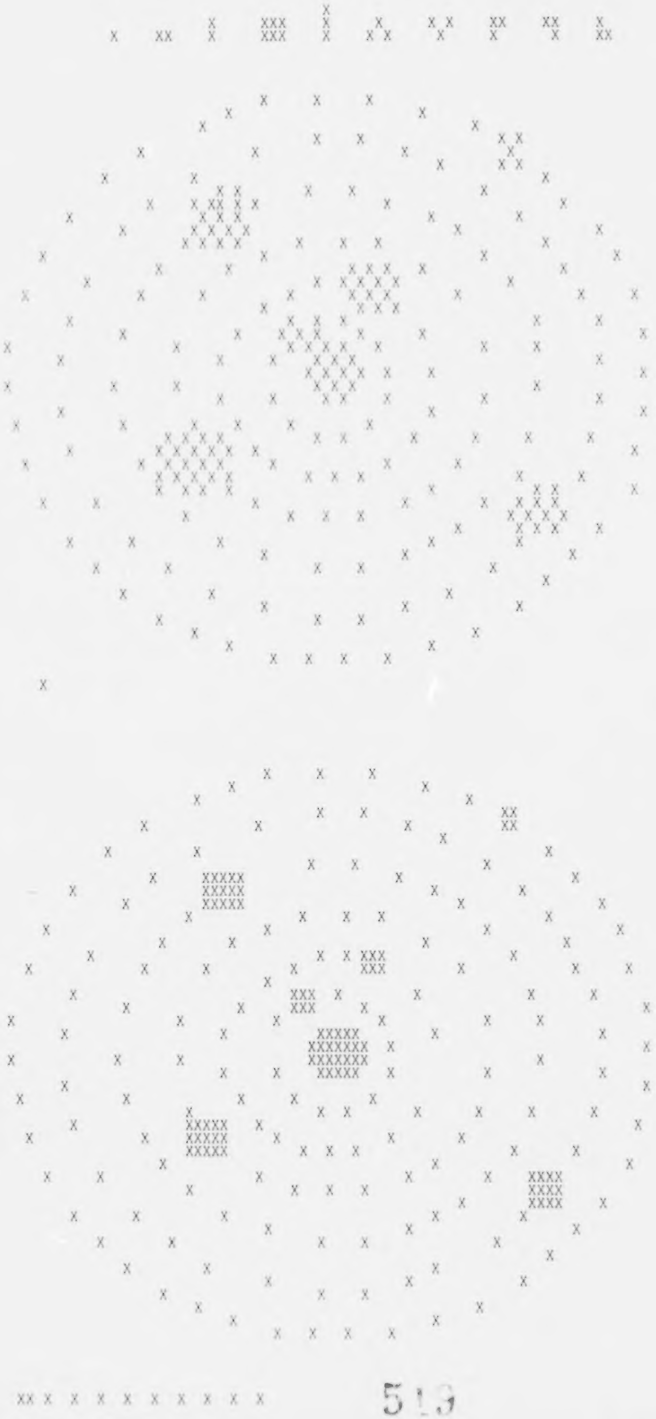
MESSAGE RECEIVED FROM THE DIRECTION 15H 21.1M +30DEG 28MIN



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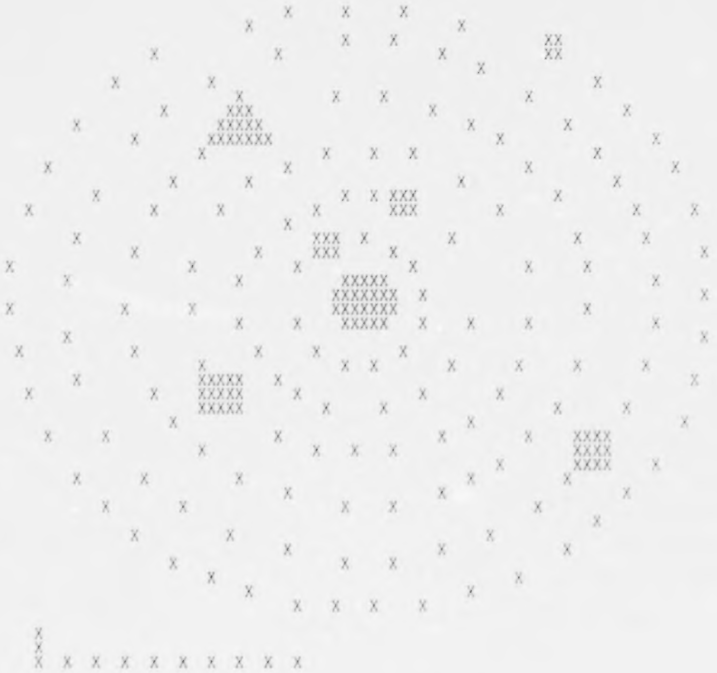

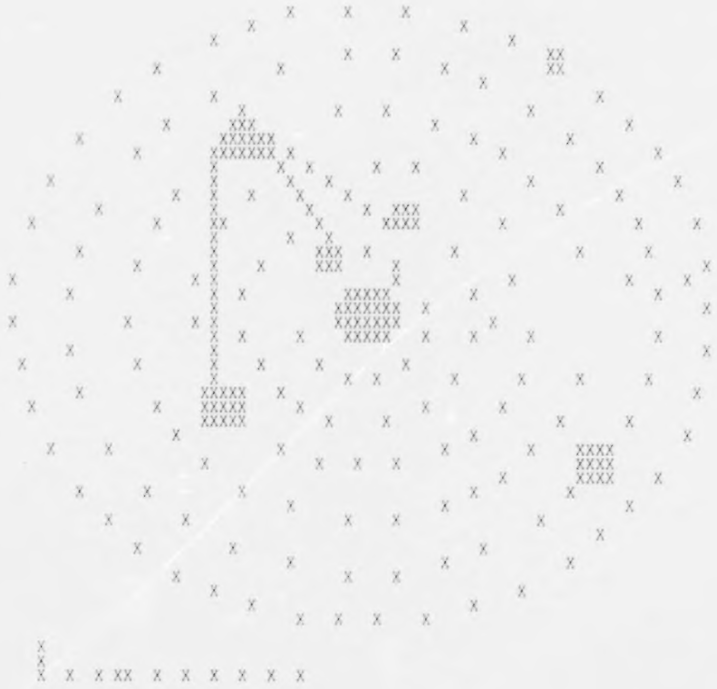

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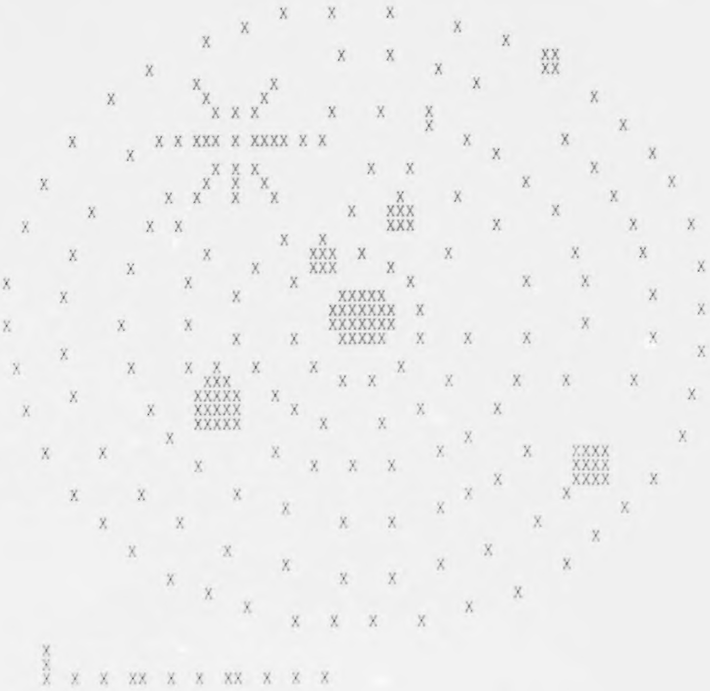

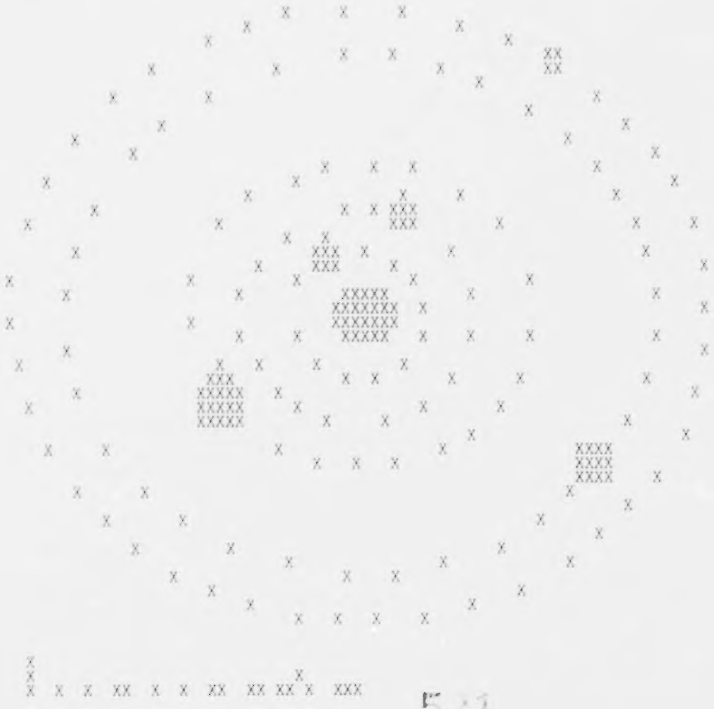

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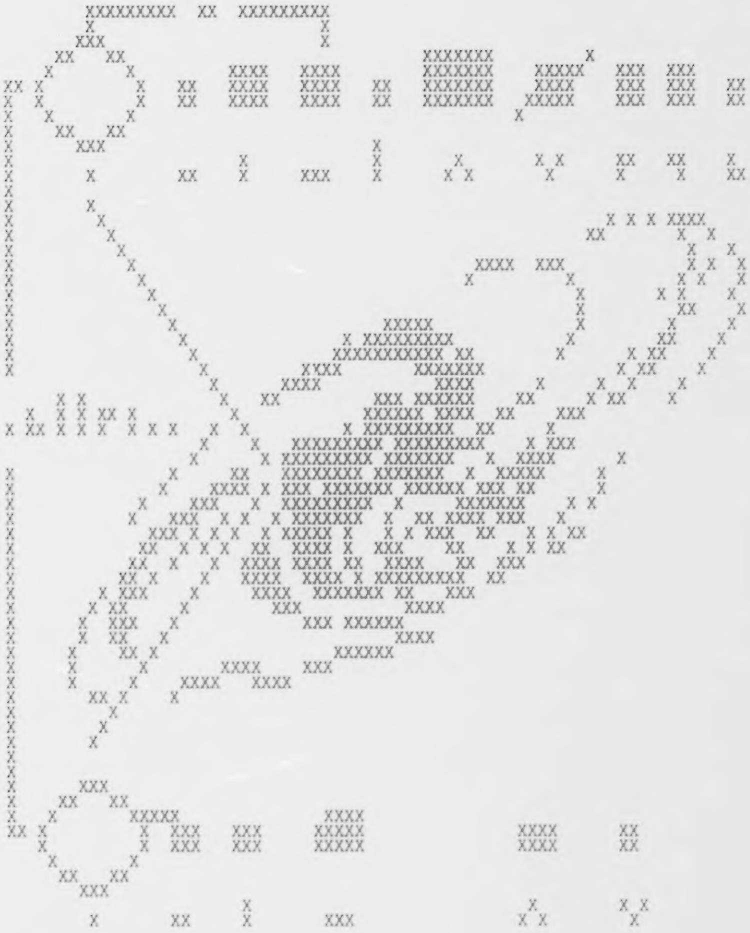

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INVENT AN ALIEN

ACTIVITY I-6

GRADE LEVEL: 3-12

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What's This Activity About?

An alternative to imagining how humans would live and work on a moon or planet is to ask students to create an alien life form suited to a particular world. This activity is one of Dennis Schatz' many very successful ones. It really captures students' imagination and spirit, while teaching them about the surface conditions on other planets.

What Will Students Do?

Applying their knowledge of conditions on planets, students devise an alien life form suited to the temperature, gravity, terrain, radiation exposure, composition, and atmosphere of a known (or unknown!) moon or planet. They describe the alien to their classmates via oral reports, writing, art, and/or models.

Tips and Suggestions

- This activity works very well after students have learned about particular planetary characteristics and is a good final project.
- It can also be done as a fun introduction to the planets, and then used to review preconceptions. It is easily extended into creative writing and art assignments.
- As the activity suggests, it is helpful to focus students on the features an alien would need before they begin to make their model. Have students make a plan for their creature, or do the writing assignment, before they build their creature.
- For older students, do this exercise as a group activity to encourage collaborative problem-solving.
- Have students "introduce" their creature to younger students.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Exobiology	Imagining	Systems and Interactions
Planetary, satellite, and/or stellar conditions	Describing	Models and Simulations
	Reasoning	
	Explaining	

INVENT AN ALIEN

Activity One provided students with an understanding of how astronomers use observations of earth to infer information about other planets. In Activity Two, students research and learn about the planets using language and art skills. The scientific accuracy of their alien beings is not as important as the reasoning processes they go through to construct them.

CONCEPT

Creatures require specific adaptations to sustain life in their environment.

OBJECTIVES

Students will:

- develop an in-depth understanding of one planet in our solar system, as well as a general overview of all the planets.
- use library resources.
- construct a model of an alien being that could exist on another planet in our solar system.
- use divergent thinking skills and creativity.

MATERIALS

research materials
any common items found around the house
paper and pencil
small box or bag
planet name slips

PROCEDURE

Advanced Preparation:

Write the name of each planet (except Earth) on separate slips of paper. It is desirable to have more than one slip for each planet so students can see that there may be different solutions to the same problem. Place the slips of paper in a box or bag.

Inform the school librarian that the students will be doing research on the planets in the solar system. The librarian may have materials other than books that students can use for their research—the more recent the publication, the more up-to-date the information.

1. Have each student select a planet slip from the box or bag containing them. The students should not reveal to other members of the class which "world" they have.

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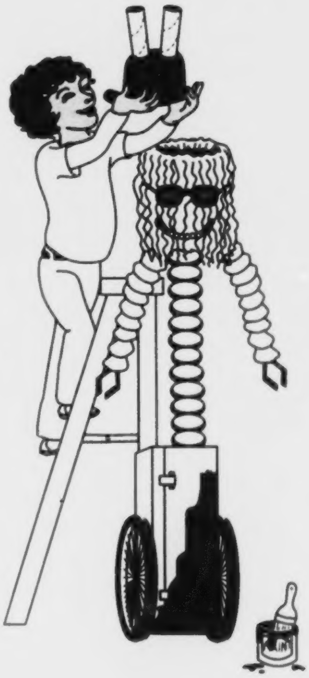
2. Inform students that their goal is to construct a model of a creature that could live in the world they selected. These should be three-dimensional models made from any materials they can find around the house. Give the students one week to 10 days to complete the task. Ask them also to write a half-page to a full-page description of their alien being, stating why it has the characteristics they selected, without revealing the name of the planet.

3. Discuss some of the requirements for a "being" to exist in any given world. Help students brainstorm a list of needs that creatures require for survival. These could include:
   - a means to get food
   - a way to move
   - a way to breathe
   - a way to reproduce
   - a means to maintain proper body temperature
   - other means to sense the environment (equivalent to our five senses)
   - other suggestions they may have, such as the effects of a gravitational pull that is much larger or smaller than we experience

   Teacher's Note: You may find that this is a good discussion to have again after students have researched the nature of their worlds, but before they actually start constructing their alien beings.

   This activity will require that the students use the library resources available at the school and in the community to determine the characteristics of the planets. If possible, you should examine what references the libraries in your area have. Good resources could include:
   - encyclopedias (preferably no more than three years old)
   - *Odyssey Magazine*
   - *National Geographic*
   - *Astronomy Magazine*
   - recent books and videos about the planets (less than five years old)



4. On the day that the alien beings are due, have students put their models on display around the room with a description of their alien beings in front of each. Remind students that their descriptions should not name the planet of their creature.

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5. Allow students the opportunity to examine each other's alien beings. Have them try to determine which planet they think each one comes from. This part of the activity can also be done as an oral presentation.
6. After the alien beings are reviewed and their home worlds revealed, have the students talk about the difficulties they experienced designing life for other worlds. Discuss with them the reasons our space probes have not found evidence of life elsewhere in the solar system.

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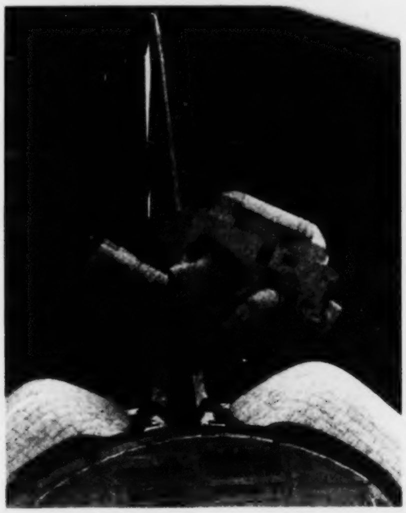

RESOURCES FOR EXPLORING SPACE EXPLORATION

by Andrew Fraknoi
Astronomical Society of the Pacific
390 Ashton Ave.
San Francisco, CA 94112

NOTE: The literature on space exploration is very large. The introductory materials we have included below are those that take an astronomical perspective or that teachers of astronomy have found useful in the past. Your librarian can probably find many other books and articles on any specific topic that you or your students want to explore.

SELECTED RESOURCES FOR TEACHERS & ASTRONOMERS

Allen, J. *Entering Space: An Astronaut's Odyssey*, revised ed. 1985, Stewart, Tabori, & Chang. A wonderful, richly illustrated introduction by one of the Shuttle astronauts.

Chaikin, A. *A Man on the Moon*. 1994, Viking Press. History of manned lunar exploration.

Clark, D. *The Cosmos from Space*. 1987, Crown. Astronomical instruments in space.

Davies, J. *Satellite Astronomy*. 1988, Horwood/J. Wiley. Astronomical observations from space.

DeVorkin, D. *Science with a Vengeance: How the Military Created U.S. Space Sciences*. 1992, Smithsonian Institution Press. Carefully researched history of how our civilian space satellites evolved from the military concerns of earlier times.

Editors of *Time-Life Books: Life in Space*. 1983, Time-Life Books. A pictorial album and text from the pages of Life magazine.

Editors of *Time-Life Books: Outbound and Spacefarers*. 1989, Time-Life Books. Part of a series on astronomy called *Voyage through the Universe*, these lavish books introduce past missions and what might be possible in the future.

Hartmann, W., et al. *Out of the Cradle: Exploring the Frontiers Beyond Earth*. 1984, Workman. An astronomer and artists showcase space exploration now and in the future.

Hawthorne, D. *Men and Women of Space*. 1992, Univelt. Short biographies of 650 U.S. and foreign astronauts and others.

Kerrod, R. *The Illustrated History of NASA*. 1986, Gallery Books.

Lewis, R. *From Vinland To Mars: 1000 Years of Exploration*. 1976, Quadrangle Books. Eloquent introduction to the history of exploration and its continuation into space.

McDonough, T. *Space: The Next 25 Years*. 1987, Wiley. Possible directions for space program.

McDougall, W. *The Heavens and the Earth: A Political History of the Space Age*. 1985, Basic Books. Widely praised history of the many factors that went into creating our push to space.

National Commission on Space: *Pioneering the Space Frontier*. 1986, Bantam. Report of a commission on America's future in space.

Nicks, O. *Far Travelers: The Exploring Machines*. 1985, NASA Special Publication 480, U.S. Government Printing Office. A his-

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tory of robot spacecraft that NASA has sent to other worlds.

Oberg, J. *Red Star in Orbit: Soviet Failures and Triumphs in Space.* 1981, Random House. An interesting history.

Sagan, C. *Pale Blue Dot.* 1994, Random House. Eloquent evocation of the excitement of planetary exploration and justifications for pursuing our dreams in space.

von Braun, W. & Ordway, F. *History of Rocketry and Space Travel.* 1975, Crowell. A classic.

Walter, W. *Space Age.* 1992, Random House. Colorful book from the public television series, focusing on history, current missions, and future plans.

Asimov, I. "The Next Frontier" in *National Geographic*, July 1976.

Banks, P. & Ride, S. "Soviets in Space" in *Scientific American*, Feb. 1989.

Biddle, W. "What Destroyed the Challenger?" in *Discover*, Apr. 1986, p. 40.

Carroll, M. "Cheap Shots" in *Astronomy*, Aug. 1993, p. 38. On cheaper missions NASA is planning with its reduced budgets.

David, L. "America in Space: Where Next?" in *Sky & Telescope*, July 1987, p. 23. On the report of the Commission on Space and future projects.

Dworetzky, T. "Return of the Shuttle" in *Discover*, July 1988, p. 46. On the modifications and first flight after the Challenger disaster.

Eicher, D. "A New Era in Space: Space Astronomy for the 1990's" in *Astronomy*, Jan. 1990, p. 22. On what was planned for the 1990's, with an excellent mission table.

Hoffman, J. "How We'll Fix the Hubble Space Telescope" in *Sky & Telescope*, Nov. 1993, p. 23. A preview by the astronaut-astronomer who would be one of the key "repair-men."

Lovece, J. "The Impending Crisis of Space Debris" in *Astronomy*, Aug. 1987, p. 6.

Lowman, P. "Regards from the Moon" in *Sky & Telescope*, Sep. 1992, p. 259. A letter from a future Moon-base tells about what science can be done from the Moon.

Maran, S. "ASTRO: Science in the Fast Lane" in *Sky & Telescope*, June 1991, p. 591. On an x-ray and UV observatory in the Space Shuttle.

van Allen, J. "Space Science, Space Technology, and the Space Station" in *Scientific American*, Jan. 1986. Prophetic article by a space scientist on how the Space Station budget will overwhelm the meager budgets for more worthwhile space projects.

Williams, J. "Built to Last" in *Astronomy*, Dec. 1990, p. 36. On computers aboard spacecraft.

The July 1989 issue of *Astronomy* magazine was a special celebration of the 20th anniversary of the first lunar landing.

See the bibliographies on the solar system in general, on the Moon, and on each of the planets in the activities section of the Notebook for readings about the missions to the planets (such as Voyager, Viking, Magellan, etc.)

READINGS ON REALISTIC SPACE TRAVEL IN THE FUTURE

Calder, N. *Spaceships of the Mind.* 1978, Viking. Very nice illustrated summary of proposed interstellar craft.

Darling, D. "Star Trek: The Adventure Begins" in *Astronomy*, Mar. 1987, p. 94; "Star Trek: Interstellar Space Flight" in *Astronomy*, Apr. 1987, p. 94.

Forward, R. & Davis, J. *Mirror Matter.* 1988, John Wiley. On space travel using antimatter.

Friedman, L. *Starsailing: Solar Sails and Interstellar Travel.* 1988, John Wiley. On using the Sun's radiation for propulsion.

Krumenaker, L. "Visionaries Swap Pointers on

Star Flight" in *Science*, vol. 266, p. 212 (Oct. 14, 1994). On a conference considering robot space probes to nearby stars.

Mallove, E. & Matloff, G. *The Starflight Handbook*. 1989, John Wiley. Best popular-level introduction.

Nicolson, I. *The Road to the Stars*. 1978, Morrow. Also an introduction.

Patton, P. "Daedelus: Design for a Spaceship" in *Astronomy*, Oct. 1983, p. 6.

SELECTED READINGS FOR STUDENTS

Grades 4-6

Asimov, I. *Rockets, Probes, and Satellites*. 1988, Gareth Stevens.

Asimov, I. *The World's Space Programs*. 1990, Gareth Stevens.

Asimov, I. *Piloted Space Flights*. 1990, Gareth Stevens.

Asimov, I. & Giraud, R. *The Future in Space*. 1993, Gareth Stevens.

Barett, N. *Space Shuttle*. 1985, Franklin Watts.

Berliner, D. *Living in Space*. 1993, Lerner Publications.

Branley, F. *From Sputnik to Space Shuttles*. 1986, Crowell.

Briggs, C. *Women in Space: Reaching the Last Frontier*. 1988, Lerner. Lives and work of women astronauts and cosmonauts.

Couper, H. & Henbest, N. *Space Probes and Satellites*. 1987, Franklin Watts.

Reigot, B. *Space Traveler: To Space and Back on the Shuttle*. 1983, Scholastic.

Ride, S. & Okie, S. *To Space and Back*. 1986, Lothrop, Lee, and Shepard. As told by America's first woman astronaut.

A few recent articles in *Odyssey* magazine:

Algozin, M. "Happy Birthday Space Shuttle" Apr. 1991, p. 4.

Barnes-Svarney, P. "Spacecraft at the Rim" Oct. 1994, p. 11. On Voyager, Pioneer missions.

David, L. "Space Rescue: Getting Home in a Hurry" Feb. 1993, p. 4.

Grashnek, V. "What Can We Learn from Spaceflight Research" Feb. 1993, p. 19.

Hastings, G. "My Seven Days as a Cosmonaut in Training" Nov. 1992, p. 36.

Logsdon, J. "Sputnik I: First Traveler in Space" May 1993, p. 4.

Logsdon, J. "Lunar Legacy: Apollo in Historical Perspective" Nov. 1993, p. 4.

Walz-Chojnacki, G. "It Came from Outer Space" Dec. 1990, p. 10. On the tomato seeds that came back from space and were distributed to classrooms.

Welsbacher, A. "Partners in Space: Products, Research and Benefits" May 1992, p. 4. On spinoffs from space exploration.

"Interview with Astronaut Kathy Sullivan" Feb. 1992, p. 30.

Grades 7-9

Apfel, N. *Space Station*. 1987, Franklin Watts. Primer on space flight, past and future.

Darling, D. *Where Are We Going in Space?* 1984, Dillon Press.

Embury, B. *The Dream is Alive*. 1990, Harper & Row. Beautiful color book based on the IMAX film.

Moore, P. *Space Travel for the Beginner*. 1988, Cambridge U. Press. A guide to space missions from early rockets through Moon and planet probes to the future.

O'Connor, K. *Sally Ride and the New Astronauts: Scientists in Space*. 1983, Franklin Watts. Profiles some of the new women astronauts and previews some Shuttle missions.

Pogue, W. *How Do You Go to the Bathroom in Space*, 2nd ed. 1991, Tom Doherty

Associates. 221 questions and answers about space flight and exploration.

Smith, C. *One Giant Leap for Mankind.* 1985, Silver Burdett. Introduction to the space program.

Vogt, G. *An Album of Modern Spaceships.* 1987, Franklin Watts.

Vogt, G. *Apollo and the Moon Landing.* 1991, Millbrook Press.

Vogt, G. *Viking and the Mars Landing.* 1991, Millbrook Press.

SELECTED AUDIOVISUAL MATERIALS

Blueprint for Space (60-min video from Finley-Holiday Films) History of space flight, narrated by Alan Shepard.

Destiny in Space (1994 IMAX film, available to individuals only on home video from 70MM Inc., 800-263-IMAX) A dramatic film (with surround sound) and fabulous images, about space exploration and the repair of the Hubble Space Telescope.

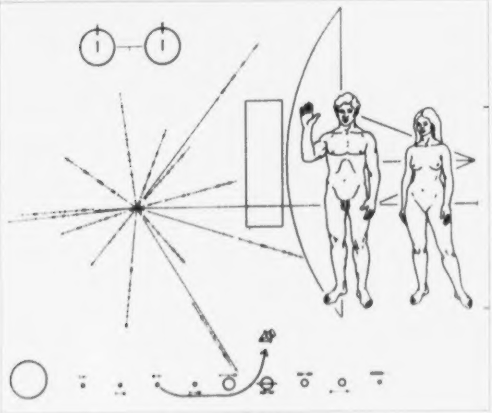
Dreams of Flight (2 videos from the Smithsonian Air & Space Museum or the Astronomical Society of the Pacific) Two 50-minute videos *To the Moon* and *Beyond the Moon* chronicle the history of manned and robotic space exploration.

Hubble Space Telescope: Rescue in Space (1994 video from Finley-Holiday Films)

Moon Shot (2 videos, 192 min., from the Astronomical Society of the Pacific) Narrated by Alan Shepard and Deke Slayton, this is the story of the U.S. space program.

Excellent slide sets of some planetary and Shuttle missions are available from Finley Holiday Films at very reasonable prices.

Many of the recent and older NASA films are available on videotape from NASA CORE (see the list of addresses in the Resources Section of the Notebook).



RESOURCES FOR EXPLORING THE SEARCH FOR EXTRATERRESTRIAL LIFE

by Andrew Fraknoi
Astronomical Society of the Pacific
390 Ashton Avenue
San Francisco, CA 94112

Books and articles marked with a • are especially useful for those just becoming familiar with the subject.

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

- • Drake, F. & Sobel, D. *Is Anyone Out There?* 1992, Delacorte Press. Well-written autobiography of Frank Drake, the pioneer scientist in this field, and a good introduction to the scientific search for radio signals from ET's.
- • Sullivan, W. *We Are Not Alone*, 2nd ed. 1993, Dutton/Penguin. The former science editor of The New York Times reviews the whole topic.
- Feinberg, G. & Shapiro, R. *Life Beyond the Earth*. 1980, Morrow. A physicist and a biologist speculate about all the forms that life in the universe may take. Useful for those doing an "Invent an Alien" activity. A much less academic approach is taken by Dickinson, T. & Schaller, A. *Extraterrestrials: A Field Guide for Earthlings*. 1994, Firefly Books.
- Goldsmith, D. & Owen, R. *The Search for Life in the Universe*, 2nd ed. 1992, Addison-Wesley. The definitive college textbook in this area. An excellent, well-written reference.
- • McDonough, T. *The Search for Extraterrestrial Intelligence*. 1987, John Wiley. A basic, good-humored, popular introduction to the field, good for beginners. Could be read by middle-school or older students.
- • Sagan, C. *Cosmos*. 1980, Random House. *Pale Blue Dot*. 1994, Random House. In both books, Sagan eloquently explains and argues for the search.
- Bova, B. & Preiss, B., eds. *First Contact: The Search for Extraterrestrial Intelligence*. 1990, New American Library. Intriguing collection of articles by scientists, hobbyists, and science fiction writers.
- Dick S. *The Plurality of Worlds: The Extraterrestrial Life Debate*. 1982, Cambridge U. Press.; and Crowe, M. *The Extraterrestrial Life Debate: 1750-1900*. 1986, Cambridge U. Press. Two books giving the history of humanity's thinking about life elsewhere.
- • Shostak, S. "Listening for Life" in *Astronomy*, Oct. 1992, p. 26. A good introduction to the major NASA project that began on Columbus Day 1992 and was then cut by Congress.
- Sagan, C. "The Search for Extraterrestrial Life" in *Scientific American*, Oct. 1994, p. 93. Part of a special issue devoted to cosmic evolution.
- • Tarter, J. "Searching for Them: Interstellar Communications" in *Astronomy*, Oct. 1982, p. 10. Sets the background for the modern search; by the woman scientist who now heads half the NASA project.
- Naeye, R. "SETI at the Crossroads" in *Sky & Telescope*, Nov. 1992, p. 507. Good review.
- The Jul/Aug 1992 issue of the Astronomical Society of the Pacific's *Mercury* magazine

was devoted to the topic of SETI and has a good report on past and present searches. Also includes a long bibliography on SETI for those who need further sources.

Chyba, C. "The Cosmic Origins of Life on Earth" in *Astronomy*, Nov. 1992, p. 28. On recent work indicating that steps toward life may have begun in space.

SELECTED READINGS FOR STUDENTS

Grades 4-6

Asimov, I. *Is There Life on Other Planets?* 1989, Gareth Stevens.

Darling, D. *Other Worlds: Is There Life Out There?* 1985, Dillon Press.

Fradin, D. *The Search for Extraterrestrial Intelligence.* 1987, Children's Press.

The July 1993 issue of *Odyssey* magazine (from Cobblestone Publishing) was devoted to the topic of SETI, including an interview with Jill Tarter.

Grades 7-9

Alschuler, W. *UFO's and Aliens.* 1991, Avon Books. Despite the title, this is a responsible introduction to thinking about life elsewhere.

Darling, D. *Could You Ever Meet an Alien?* 1990, Dillon Press.

Gutsch, W. *The Search for Extraterrestrial Life.* 1992, Crown.

Moche, D. *Life in Space.* 1979, Ridge Press.

Poynter, M. & Klein, M. *Cosmic Quest: Searching for Intelligent Life Among The Stars.* 1984, Atheneum.

Articles in *Astronomy* Magazine are often quite readable for students at this level.

SELECTED AUDIOVISUAL MATERIALS

Cosmos (1980 video, Turner Home Video or Astronomical Society of the Pacific) Three episodes of this superb public television program feature ideas about SETI. This is best for the upper grades.

Is Anybody Out There? (1986 video, Coronet Films) Written by astronomer Donald Goldsmith and narrated by Lili Tomlin, this wonderful NOVA program is perhaps the best layperson's introduction to the field.

Quest for Contact (1987 video, Astronomical Society of the Pacific) Good introduction to SETI with a NASA perspective, narrated by Jill Tarter.

The Search for Extraterrestrial Intelligence (1987 slide set, Astronomical Society of the Pacific) A set of 20 slides, with captions by Frank Drake and a booklet of background information for teachers.

Murmurs of Earth (1977/1992, Warner Home Media or the Planetary Society) The audio and video record sent into deep space aboard the Voyager probes (with the collected sights and sounds of Earth) on a CD and CD-ROM format disk.

J

TOOLS OF THE ASTRONOMER

ACTIVITIES INCLUDED IN TOOLS OF THE ASTRONOMER

ACTIVITY	ESTIMATED GRADE LEVEL											
Grades	1	2	3	4	5	6	7	8	9	10	11	12
J-1. Making Measurements of Objects in the Sky Students make a simple astrolabe to measure the changing locations in the sky of the Sun, Moon and stars.				▨	▨	■	■	■	■	▨	▨	▨
J-2. Parallax—How Far Is It? Students use the method of parallax to determine the distances to various objects inside and outside the classroom.							▨	■	■	■	■	■
J-3. Hello Out There! Students walk heel-to-toe to model the concept of light travel time.						▨	■	■	■	■	▨	▨
J-4. Light and Color—Activities from the FOSTER Project Students engage in a variety of integrated activities dealing with light, spectra, color and astronomical images.					▨	■	■	■	■	■	■	■
J-5. Seeing the Invisible: Studying Infrared and Ultraviolet Radiation Students demonstrate the existence of IR and UV radiation							■	■	■	■	▨	▨
J-6. Infrared Light Students use TV remote control units to investigate the properties of infrared radiation						▨	■	■	■	■	▨	▨
J-7. Spectroscopes and Spectrometers Students observe the different patterns and colors in the spectra of different light sources using a diffraction grating.				■	■	■	■	■	■	■	▨	▨
J-8. Light Collecting Model Students cover circles of various sizes with pennies to find out how the amount of light collected by a telescope mirror depends upon the size of the mirror.			▨	■	■	■	■	▨	▨			
J-9. What Makes Good Viewing? Students investigate the effect of wind, heat, light pollution and fog on the use of telescopes.				■	■	■	■	■	▨	▨	▨	
J-10. Building an Optical Telescope; Making a Simple "Parabolic" Reflector Students construct simple refracting telescopes, and observe how an umbrella covered with aluminum foil can focus radio waves.						■	■	■	■	■	▨	▨

■ - Grade levels recommended by authors ▨ - Can be extended to these grade levels.

About the Activities:
Tools of the Astronomer

Key Ideas in "Tools of the Astronomer"

- All that we know about the universe comes from the study of light and other forms of electromagnetic radiation.
- Our eyes are detectors of light and much of what we know about the universe is derived from the images that light forms on our retinas.
- The earliest astronomical tools were aids to naked eye observations. These instruments helped people guide their ships across featureless seas, determine when to plant crops, and when to honor their gods.
- Naked-eye instruments were developed to their highest degree by Tycho Brahe in the 16th century. His observations ushered in a new era in astronomy.
- The *Benchmarks* recommends that students start using binoculars and telescopes to observe the Moon, stars, and planets at the 3-5 grade level.
- In grades 6-8, the *Benchmarks* recommends that students should use a variety of astronomical tools, including star finders, telescopes, computer simulations of planetary orbits, and planetariums.
- By the end of 12th grade, students should know about increasingly sophisticated tools used to observe the universe across the entire electromagnetic spectrum, as well as computers for analyzing data and simulating natural processes, space probes to explore the planets, and subatomic particle accelerators to create conditions like those near the beginning of the universe.

All that we know about the universe beyond our home planet comes from the study of light and other forms of electromagnetic radiation. Knowledge of the stars, planets, comets, and even our neighboring Moon comes from the subtle differences in the light that we receive from these bodies—the color, brightness, and direction of the light.

Although they are not "tools," since they do not extend our senses, our eyes are certainly detectors of light, and much of what we know about the universe is derived from the images that light forms on our retinas. The daily motions of the Sun, Moon, and stars, the wanderings of the planets, and the changes in these patterns that take place monthly and seasonally can all be observed with the naked eye.

The first significant tools used by astronomers were invented long before Galileo first turned his crude telescope on the Moon and Jupiter. These aids to naked eye observation allowed people to accurately measure, record, and predict the positions of celestial bodies. From the huge monoliths of Stonehenge to the mariner's astrolabe, these important instruments helped people guide their ships across featureless seas, determine when to plant crops, and when to honor their gods. Such naked-eye instruments were developed to their highest degree in the 16th century by Tycho Brahe whose observations led to the first reliable estimates of the relative distances to the Moon, Sun, and comets, and an understanding of the elliptical paths taken by the planets. These measurements shattered the belief that the planets traveled around the Sun within crystal spheres, and ushered in a new era in astronomy.

For anyone who has seen the craters of the Moon or the rings of Saturn, the most spectacular of modern scientific instruments for astronomy has, of course, been the telescope. It is difficult to describe in words why such a sight in a small telescope is more impressive than a picture of the same object in a book, but the difference in the experience is unmistakable. Seeing "the real thing" is an unforgettable experience. That is why the *Benchmarks for Science Literacy* recommends that students start using binoculars and telescopes to observe the Moon, stars, and planets as soon as possible—at the 3-5 grade level. By the end of fifth grade, students should know (from personal experience) that "Telescopes magnify the appearance of some distant objects in the sky, including the Moon and the planets. The number of stars that can be seen through a telescope is dramatically greater than can be seen by the unaided eye." (*Benchmarks*, page 63.) By the end of the eight grade students are also expected to have viewed various features of the Moon and planets. (*Benchmarks*, page 360.)

In grades 6-8, the *Benchmarks* recommends that students should use a variety of astronomical tools. "Student access to star finders, telescopes, computer simulations of planetary orbits, or a planetarium can be useful at this level." (*Benchmarks*, page 63.) And by the end of 12th grade, students should know that "Increasingly sophisticated technology is used to learn about the universe. Visual, radio, and x-ray telescopes collect information from across the entire spectrum of electromagnetic waves; computers handle an avalanche of data and increasingly complicated computations to interpret them; space probes send back data and materials from the remote parts of the solar system; and accelerators give subatomic particles energies that simulate conditions in the stars and in the early history of the universe before stars formed." (*Benchmarks*, page 65.)

The activities in this section include a full range of instruments, from a naked-eye astrolabe and the use of parallax for measuring the distances to objects, to the use of telescopes and spectroscopes, and even the observation of infrared and ultraviolet light that is invisible to the naked eye. These activities are designed to help your students not only use astronomical instruments, but also to understand how they work to extend our senses.

BACKGROUND:

TOOLS OF THE ASTRONOMER

For thousands of years, the human eye was all that was needed to observe the night sky. But when Galileo turned his crude telescope to the skies in 1609, he could suddenly see wondrous things—craters on the Moon, dark spots on the surface of the Sun, tiny moons moving around Jupiter—things that no one else had ever seen. Since then, astronomers have developed increasingly powerful telescopes to learn more about the planets, stars and galaxies that make up our universe. Some telescopes collect and focus light using a glass lens through which light passes (refracting telescopes), while others use a glass mirror from which it is reflected (reflecting telescopes).

In either case it is the area of the lens or mirror which is the crucial factor in determining how much light a telescope can collect; and if you collect more light, you can see fainter objects. Which will collect more water in a rainstorm, a small pail or a large one? Similarly, light from planets, stars and galaxies is constantly "raining down" on Earth, and larger telescopes, acting like "light buckets," will collect more light than smaller ones.

There's a limit to how big you can make lenses. Flaws develop in the glass that ruin it for astronomy. The largest refracting telescope in the world, at the Yerkes Observatory in Wisconsin, has a lens that is 40 inches across. Reflecting telescopes are not as limited by flaws in the glass, since light bounces off an aluminum coating applied only to the curved surface of the glass—so only the quality of the surface matters. For a long time, the largest reflecting telescope in the world was at Palomar Observatory in Southern California. The mirror, made in the 1940s, is 200 inches (five meters) in diameter. Making larger mirrors required so much glass that the mirrors sagged under their own weight and couldn't be used for astronomy.

But, new technologies developed in the 1980s have created an explosion of larger mirrors. Some use a segmented design, in which a number of smaller mirrors fit snug up against one another, acting like a single larger mirror. The Keck Telescope in Hawaii is the best example, with 36 hexagon-shaped mirror segments, each one meter across, that fit together like bathroom tile. With the help of a computer-controlled mechanism to maintain their overall shape, they act like a single mirror ten meters across, making the Keck the largest telescope now in use. Other new techniques involve innovative ways to lighten the amount of glass used in a large mirror. Several new telescopes, some eight-meters in diameter, are currently being built with these new techniques.

These telescopes collect and focus what is called visible light. But there is a wide range of other types of light (invisible to our eyes) given off by objects in the universe. Together, they are known as electromagnetic radiation. Astronomers normally speak of each different type of light as having a different wavelength. Think of a wave on the surface of a pond. It has crests and troughs where the water is slightly higher and slightly lower, respectively, than the height of the undisturbed water. The distance between crests is called the wavelength of the wave. The entire pattern of crests and troughs moves across the water at a definite speed. A fisherman standing on the shore of the pond sees the float on his line bob up and down as the crests and troughs go by. The number of crests which pass the float each second is called the frequency of the wave.

Electromagnetic waves are similar to water waves in many respects. They can have any value of wavelength; those with the shortest wavelengths (one trillionth of a meter) are called gamma-rays, those with the longest (ranging from millimeters to hundreds of meters) are radio waves. Visible light falls somewhere in the middle, with an average wavelength of five ten-thousandths of a millimeter. You could put 50 visible light waves end to end across the thickness of a sheet of household plastic wrap. While wavelengths and frequencies differ for different kinds of electromagnetic waves, the speed at which each travels through empty space is the same for all wavelengths, 300,000 kilometers per second (186,000 miles per second), the so-called speed of light.

Astronomers have built a bewildering array of telescopes to observe all the different wavelengths of light coming from celestial objects. Some electromagnetic radiation, like visible light and radio waves, can be seen by telescopes on the ground; others, like x-rays and ultraviolet light, are absorbed by our atmosphere and can only be observed from space. Another major problem for all telescopes built on the ground is interference from man-made sources. For example, the glow from city lights can make it difficult to see faint objects with nearby visible-light telescopes. In addition, "blurring" by our atmosphere also degrades the quality of visible-light images of the sky. To get around both these problems, observatories tend to be built atop remote mountains, far from cities and at altitudes that get above enough of the Earth's atmosphere to lessen the blurring.

Because of their longer wavelengths, radio waves are not effected by the Earth's atmosphere, but everything from cellular phones to ham radios and even electrical appliances can interfere with the detection of faint radio signals from space. Telescopes in space have none of these problems, although they are difficult and expensive to launch, maintain and operate. And if something breaks, you can't just walk over to the telescope and fix it. Over the years, astronomers have studied the sky at virtually every wavelength region, some in more detail than others. We have learned so much more about stars, galaxies and the universe as a whole than we ever could have if we had only looked at the sky in the visible light to which our eyes are tuned.

There are several ways in which astronomers use telescopes to find out about the universe. One is to study images of the sky, noting the brightness or position of celestial objects, looking for changes over time or differences between objects. At first, astronomers merely drew pictures of what they saw as they looked through the telescope. Later they attached cameras to their telescopes; the ability to take long time exposures with photographs meant that more light could be collected and fainter objects seen. Today, electronic detectors, called CCDs, have replaced photographic cameras. These new detectors, similar to, but more sophisticated than home video cameras, can collect even more light per second than is possible with photographs, providing more detailed images of even fainter objects. In addition, the electronic images are stored as digital data, which can be readily "processed" and enhanced using computers to bring out even more detail.

The light from a celestial object often contains a surprising amount of information about the source that gave it off. White light on Earth spreads out into its component "colors" when it passes through a prism or raindrops. Similarly, light from a celestial object, like a star, can be spread out and separated according to wavelengths, with an instrument called a spectrograph. By studying how much light is present at each wavelength in the light from the star, astronomers can tell what atoms and molecules it's made out of. That's because every atom and molecule will absorb or emit light only at certain wavelengths. The pattern of which wavelengths are absorbed or emitted is like a fingerprint, which uniquely identifies each atom or molecule from every other. Thus if you see something at a wavelength that corresponds to hydrogen, for example, you know that hydrogen must be present in the star. Careful analysis of these "fingerprints" in the light from celestial objects (called spectroscopy) can also tell astronomers what their temperature is, how fast they're spinning and whether they're moving through space.

Almost every detail we know about the planets, moons, stars and galaxies in the night sky we have learned using telescopes. But making observations is only part of the story. Astronomers compare their observations with predictions based on models or theories of what a star or galaxy is and how each changes with time. These models and theories can get quite complicated, requiring the most sophisticated computers available. If the observation agrees with a prediction, it lends support to the theory. If it doesn't agree, astronomers need to go back and see what is wrong with the theory that gave an incorrect prediction. In addition, a theory's prediction will often inspire astronomers to make new or more sophisticated observations, hoping to prove or disprove the theory or model. Astronomy advances through this constant interplay between observation and theory.

In a way, it's really surprising that we know as much as we do about celestial objects, considering that we can't touch a star or a galaxy. We can't poke it and see what happens, or pick it up and look at it from different angles. Yet, with large telescopes, sophisticated computers and sensitive detectors, we have learned an amazing amount about the universe.

MAKING MEASUREMENTS OF OBJECTS IN THE SKY

ACTIVITY J-1

GRADE LEVEL: 6-9

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What's This Activity About?

This series of activities develops a simple instrument for students to use in a variety of experiments related to solar motion, seasons, the Moon's motion through the stars, and the Big Dipper's motion around Polaris.

What Will Students Do?

Students first create a simple astrolabe from a copy master with which to measure altitudes and angles, and then use that device to measure the angle of the Sun during the day (by projection only, not directly). They can use the protractor to measure the Moon's position relative to nearby stars, and watch as the Moon moves during the night. Finally, they can compare the altitude of a star in the Big Dipper with the (constant) altitude of Polaris.

Tips and Suggestions

- For the Sun Observing activity, reinforce for your students the danger of looking directly at the Sun—at any time, not just during an eclipse. The activity does include a warning, but extra warnings are always appropriate here.
- This activity is related to "The Reasons for Seasons" in the section *Sun and Seasons*. The astrolabe created can also be used for "What's Your Latitude?" in the section *Star-Finding and Constellations*.

What Will Students Learn?

Concepts

Measuring angles
Daily motion of the Sun and Moon
The rotation of the sky

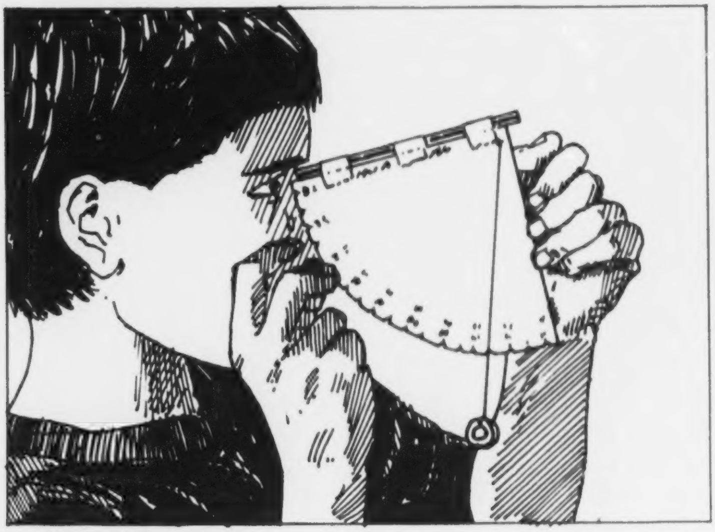
Inquiry Skills

Observing Systematically
Measuring
Recording
Evaluating
Comparing

Big Ideas

Patterns of Change

MAKING A SIMPLE ASTROLABE



Science Themes
ancient astronomy
astronomy
geometry

Science Skills
following a procedure
instrument-making

Time Frame
one class period to construct astrolabe

Materials
- ☐ *cardboard, manila file folder, or other stiff paper*
- ☐ *a piece of dark thread or string 30 cm long*
- ☐ *small weight, such as a metal washer*
- ☐ *a plastic drinking straw*
- ☐ *copies of the SRS astrolabe drawing*
- ☐ *glue or paste*
- ☐ *scissors*
- ☐ *cellophane tape or masking tape*
- ☐ *paper punch*

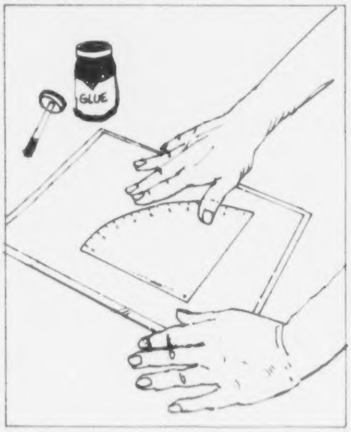
Introduction

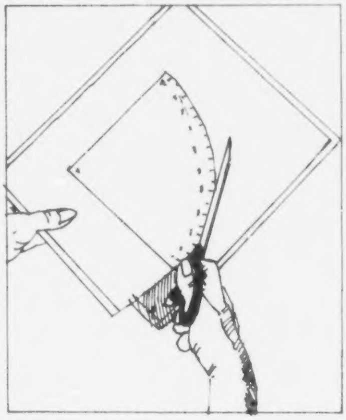
Historically, astrolabes refer to a range of measuring and calculating devices that developed over one thousand years ago to measure time, and to calculate a person's location on the earth. Astrolabes may have originated with the ancient Greeks. The earliest surviving examples, constructed by Arab and Persian craftsmen, come from the 9th through the 11th centuries. These early astronomical instruments were able to measure the angular height, or altitude, of stars above the horizon. Also, an observer could use a single astrolabe measurement to calculate the time of night if he or she knew the current date.

The astrolabe you will construct in this *Doing Science* project will measure both the altitude of objects above the horizon, and the angle separating two celestial objects in the sky.

The Activity

1) Glue your copy of the astrolabe drawing to a piece of cardboard or file folder. Cut the astrolabe out with a scissors.





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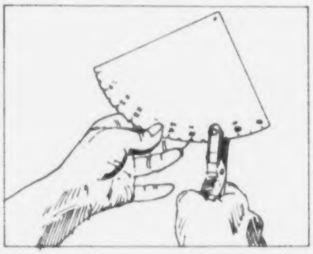
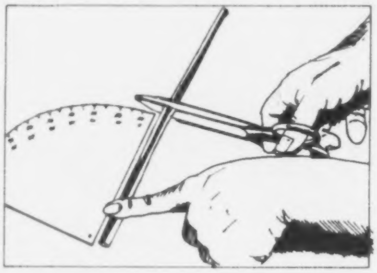
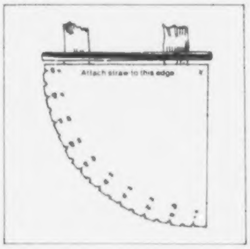
2) Using a scissors or paper punch, carefully make a small notch at each of the lines marked along the curved edge of the astrolabe. These notches will be handy when you are measuring the angle between two celestial objects and you have to hold the astrolabe horizontally.

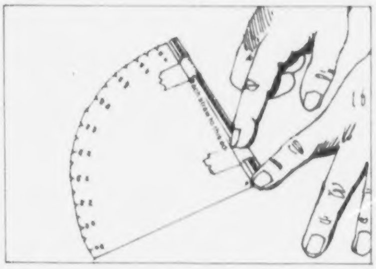
Cut a drinking straw to the same length as the sides of the astrolabe.

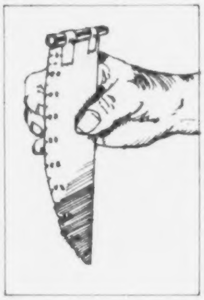




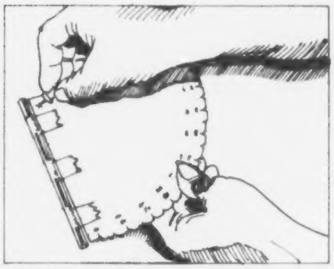
3) Tape the drinking straw to the edge of the astrolabe marked "Attach straw to this edge." Position the straw as shown.

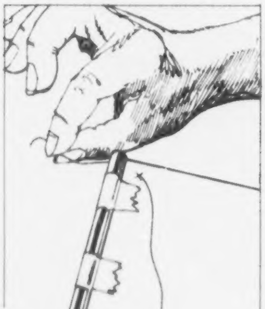

Attach straw to this edge

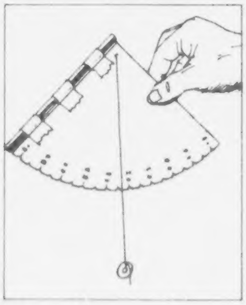




4) Carefully poke a small hole through the astrolabe where the "X" is marked, pass the string through it, and either knot that end of the string, or tape it to the blank side of the cardboard. Tie the small weight to the opposite end of the string.







Going Further

You may wish to go to a local library to look up information on astrolabes, which were popular throughout the middle ages and the early modern period. Geoffrey Chaucer, the great 14th century English poet, once wrote a guide for his son on how to use an astrolabe because he thought them so useful. A local science museum, or astronomy department at a college or university near you may have a collection of astrolabes that you could make an appointment to see. The Adler Planetarium in Chicago, Illinois, has an extensive collection of early astronomical instruments, as does the National Museum of American History of the Smithsonian Institution in Washington, D.C. Modern astrolabes are called sextants, and are used for navigation.

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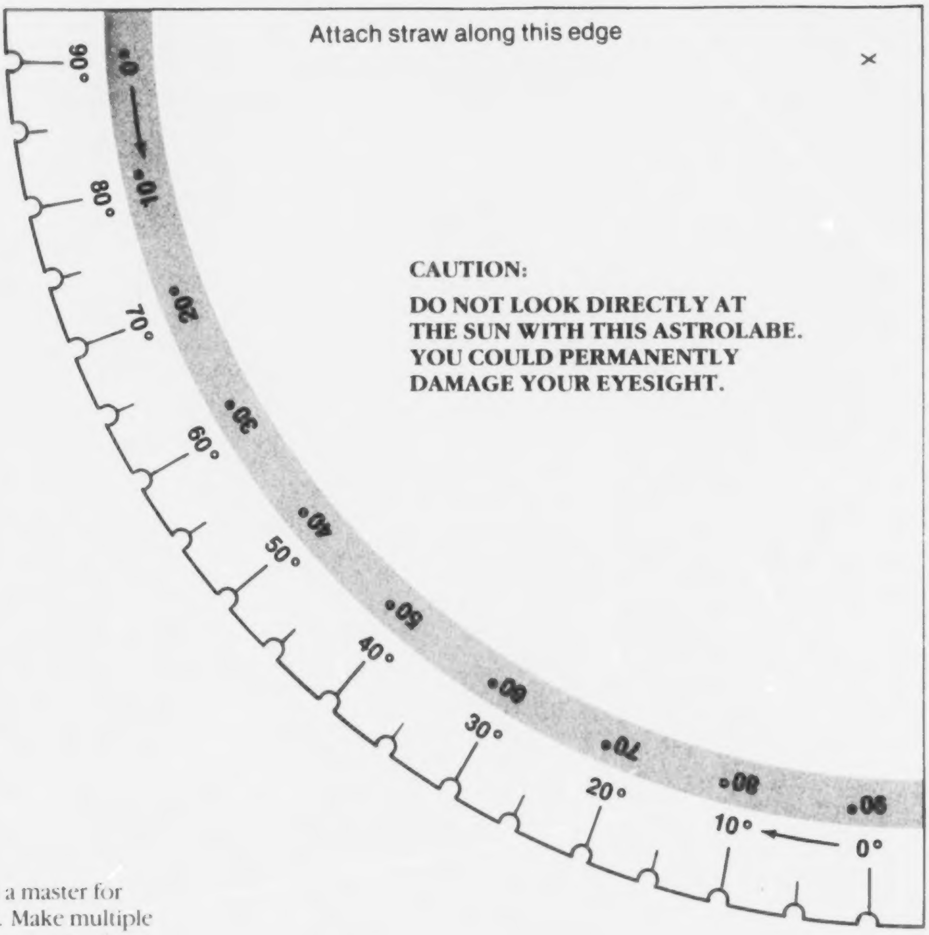
SRS ASTROLABE DS-1A


Attach straw along this edge
×
90°
80°
70°
60°
50°
40°
30°
20°
10°
0°
0°
10°
20°
30°
40°
50°
60°
70°
80°
90°

CAUTION:

DO NOT LOOK DIRECTLY AT THE SUN WITH THIS ASTROLABE. YOU COULD PERMANENTLY DAMAGE YOUR EYESIGHT.

1. Use this sheet as a master for *Doing Science 1.* Make multiple copies for use by your students. Use a copying machine that makes good, clear copies.
2. Have students paste copies on cardboard.
3. Then have students cut out Astrolabe.

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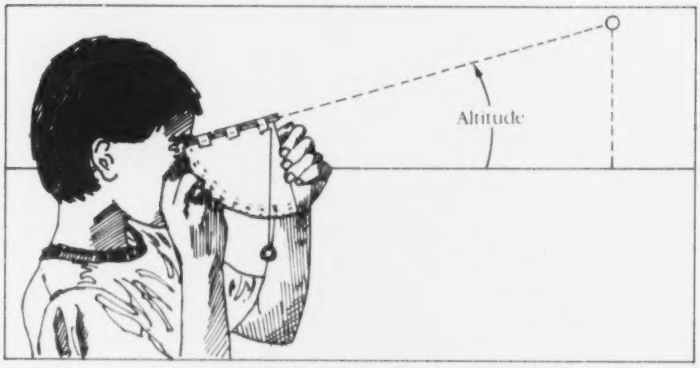
USING A SIMPLE ASTROLABE



Science Themes
astronomy
geometry

Science Skills
measuring angles
measuring angular heights

Time Frame
up to one class period to learn how to use astrolabe, additional time to make more astrolabes

Materials
astrolabe constructed in Doing Science 1
optional: construction materials in Doing Science 1 for constructing more astrolabes

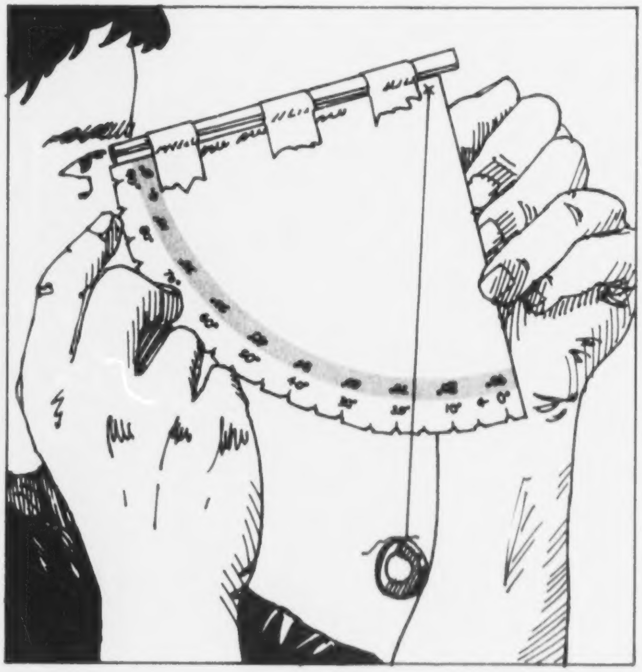
Introduction

Now that you have made a simple astrolabe it is time to try it out. Your astrolabe measures angles. For an object in the sky like the moon, the sun, or a star, it measures the number of degrees (the angle) from the horizon up to the object. See above Figure. This angle is called the angular height, or altitude.

The Activity

1) To use the astrolabe to find the angular height of a celestial object above the horizon, sight the object through the straw, and then read its altitude in degrees at the point where the string crosses the scale.

You may find it easier to sight an object through the straw by holding the astrolabe farther away from your eye than shown in the diagrams.



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Practice using your astrolabe to measure the altitude (angular height) of a tall tree, a shorter tree, a tall building or tower, a shorter building, or a street lamp.

At night practice using it with the moon, or bright stars in different parts of the sky. You may need a small flashlight to read the scale of your astrolabe.

2) To use the astrolabe to find the angle separating two stars in the sky, hold the astrolabe horizontally. Carefully bring the corner of the right angle close to your eye so that you can look along what is now the top of the astrolabe, the side that has the scale marked on it.

Still holding the astrolabe horizontally, aim the straw at the first star, and slide the string along the curved part of the astrolabe so that it lines up with the second star.

With luck, the string will be in one of the notches. If not, carefully grip the string against the cardboard between two fingers so that you don't lose your measurement. The angle you read on the scale is the angle separating two stars in the sky.

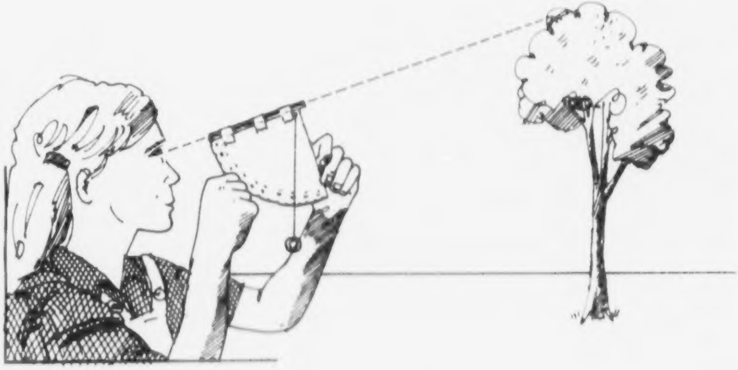
Try measuring the angle between the tops of two tall trees, or the angle between a distant tower and a building.

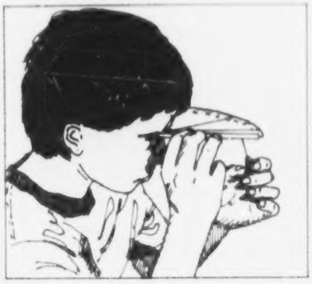
If the string is hard to work with, try putting one more small notch halfway between each of the notches you made earlier.

Discussion and Analysis

What are some of the ways that you could improve this simple astrolabe that you made? Would a larger astrolabe be easier to use than a smaller one if they both had the same number of degree marks drawn on them? Which would give more accurate measurements?

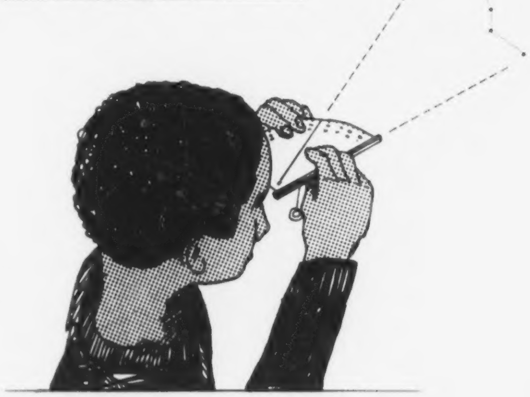
Would taking measurements of the same object several times and then averaging them give a more accurate measurement? (Remember, when averaging several numbers, first add them all together, and then divide that sum by the quantity of numbers you added together. For example, the sum of 10 + 20 + 30 + 40 is 100. When divided by 4, you get 25, the mean of the four numbers you added together.)





CAUTION:

DO NOT LOOK DIRECTLY AT THE SUN WITH THIS ASTROLABE. YOU COULD PERMANENTLY DAMAGE YOUR EYESIGHT.



Going Further

A. Construct another astrolabe like the one you just made, adding the improvements to it that you have thought of. Use both your original and your improved astrolabe to measure the angular heights of several objects, and the angles separating several other objects. Which do you think is easier to work with? Which do you think is more accurate?

B. Construct two more astrolabes: one astrolabe twice as large, and a smaller one half as large, as the one you have already made. Measure the angular heights of several objects, and the angle separating several other objects. Which do you think is easiest to work with? Which do you think is most accurate?

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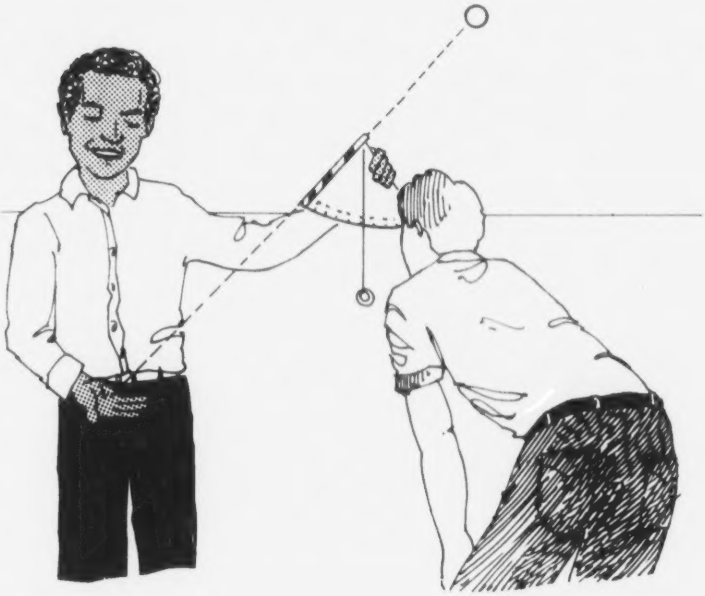
MEASURING THE MOTION OF THE SUN



Science Themes

ancient astronomy
astrometry

Science Skills

measuring angles
recording data
interpreting data

Time Frame

Observations of the position of the sun are made once a week over a period of several weeks or months. (The teacher may wish to assign teams the responsibility of measuring the sun's altitude more than once each week, and then have the teams pool their results.)

Materials

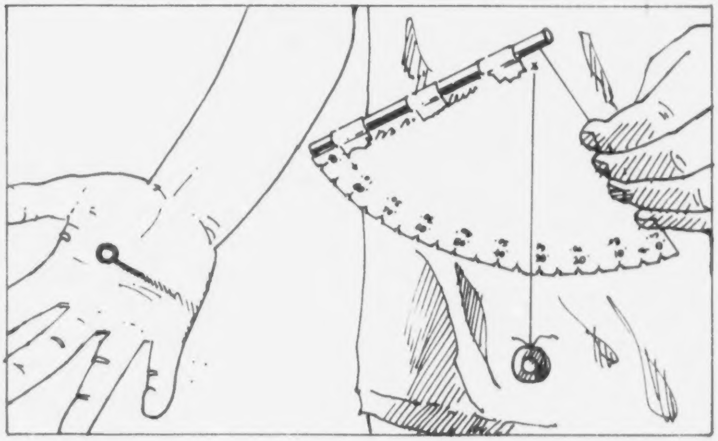
- ☐ *astrolabe constructed in Doing Science 1.*
- ☐ *a pencil and notebook to record your observations*

Introduction

Have you ever wondered why daylight lasts longer in the summer than in the winter? Why are the days longer in the summer? You can use your astrolabe to observe what is happening to the sun's path through the sky day after day. With your astrolabe you can measure how the altitude of the sun changes from season to season.

Preparation

Prior to working on this *Doing Science*, you will want to make sure that you can make accurate measurements of the altitude of celestial objects with the astrolabe. You must also practice a new technique for measuring the altitude of the sun.



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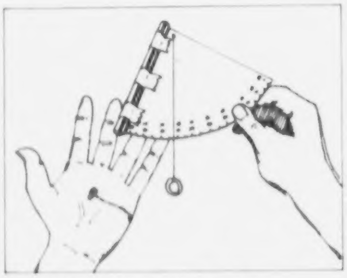
The sun is much too bright to look at directly through the astrolabe you made. You must use another technique for pointing the astrolabe at the sun.

Hold the astrolabe so that the straw points in the direction of the sun. Aim the straw so that you see the shadow of the straw on your hand. Move the straw slightly until a small circle of light forms on your hand. The straw is now pointing directly at the sun. Light from the sun passes through the length of the straw to your hand. If you tilt the straw, it will no longer point to the sun and a shadow will appear on your hand.

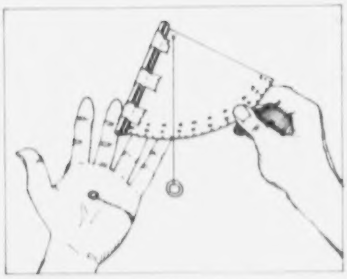
When the astrolabe is pointing directly at the sun you can read the sun's altitude (in degrees) where the string crosses the scale.

CAUTION:

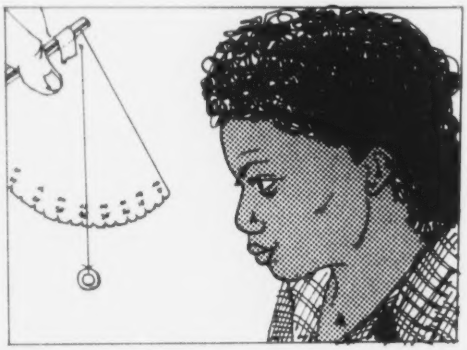
NEVER LOOK DIRECTLY AT THE SUN UNDER ANY CIRCUMSTANCES ESPECIALLY WITH BINOCULARS, TELESCOPES, OR OTHER OPTICAL DEVICES. YOU COULD PERMANENTLY DAMAGE YOUR EYESIGHT!



Astrolabe not pointing to sun



Astrolabe pointing directly at sun



The Activity

One day a week, at 12:00 noon local time, measure the altitude of the sun with your astrolabe. Make three measurements and record them in a notebook. At noontime, the sun is just crossing, or is close to, the meridian, an imaginary line that extends across the sky from north to south. The sun is at or near its highest point in the sky for that day. (You can show this with a shadow stick.)

Repeat your measurements of the sun's altitude at noontime once a week for several weeks. Your time of measurement should be close to noontime, but you can be off by several minutes and not seriously alter the results.

Discussion and Analysis

Look at your measurements of the sun's altitude over the period of several weeks. Can you detect a change in its noontime altitude? Is the altitude increasing or decreasing? Is there a pattern of change? How can you explain these changes?

Going Further

A. You may want to continue your astrolabe measurements through the school year to see how the altitude of the sun changes over the year.

B. Try making a graph of the data that the class has collected. Use the x-axis for the dates of your measurements and the y-axis for the altitude of the sun. The graph should show how the sun's altitude changes from month to month.

Date:							
Time:							
Altitude of Sun: 1.							
2.							
3.							
Mean							

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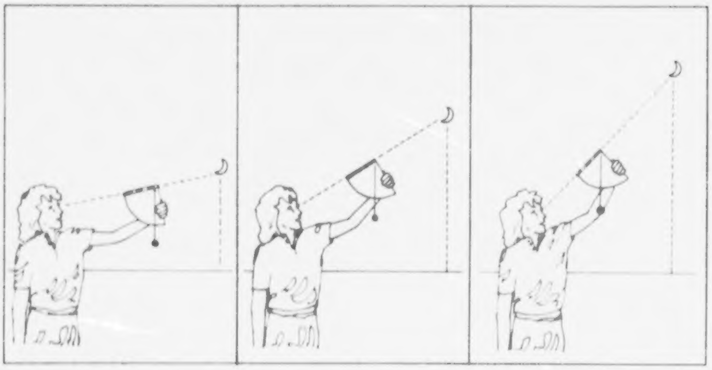
MEASURING THE MOTION OF THE MOON



Science Themes

astronomy
geometry

Science Skills

observing
measuring angles
recording data
inferring motion

Time Frame

a few minutes each day (or night) over a period of several days

Materials

- ☐ *astrolabe constructed in Doing Science 1*
- ☐ *pencil and notebook for recording data*
- ☐ *access to a wrist watch or clock*
- ☐ *paper for sketching a map of the moon in the sky*

Introduction

The ancients used the movements of the moon for their early calendars. The changes in its position and its phases (new moon, first quarter, full moon, last quarter) served as an easy way to keep track of time.

You have surely seen the moon when it is full, low in the eastern sky. You have sensed its change in position from hour to hour as it moves higher in the sky. You may even have sensed the moon's change in position in the daytime sky. Have you ever noticed any changes in the moon's position in the sky from one day to the next? or from one night to the next?

The Activity

You can measure the changes in position of the moon with your astrolabe. You can find out how much the moon moves relative to the horizon. Or you can use a planet like Venus or Jupiter as a reference point and measure how much the moon moves relative to Venus or Jupiter. Or you can measure how the moon's position changes relative to a bright star in the sky.

Daytime. Watch the sky each day to find a day when you can see the moon in the sky at the same time that the sun is there. If you find the moon low on the Eastern horizon, pick a later time to make your measurements (3-4 hours later).

Measure the altitude of the moon with your astrolabe. Note the time, and write down both its altitude and the time of day in your notebook. Record three measurements of the altitude. Compute the mean. Record also the direction of the moon along the horizon—east, southeast, south, southwest, west, etc.

For the next three days *at the same time*, measure the moon's altitude with your astrolabe. Record your data in your notebook. What do you notice about the moon's position in the sky from day to day?

Date:				
Time:				
Altitude of moon: 1.				
2.				
3.				
Mean				
Moon's direction along horizon:				
Moon's shape:				

Moon's position from day-to-day

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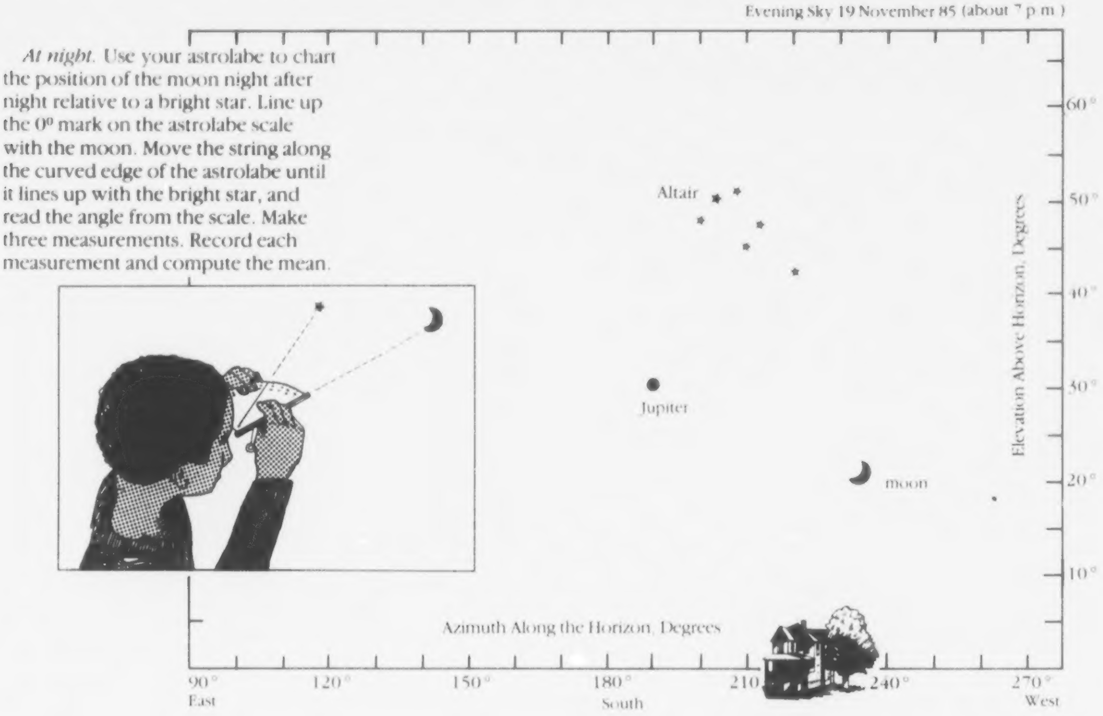
J-1, Making Measurements of Objects in the Sky

At night. Use your astrolabe to chart the position of the moon night after night relative to a bright star. Line up the 0º mark on the astrolabe scale with the moon. Move the string along the curved edge of the astrolabe until it lines up with the bright star, and read the angle from the scale. Make three measurements. Record each measurement and compute the mean.



Repeat this each night, beginning when the moon is a few days past its New phase. The table below will help you know when it will be New Moon.

The star Altair is a good reference point in the southwest sky for evenings in November and December.

The above view of the sky for 19 November will also be useful for 14-16 December about 6:30 p.m. The stars and Jupiter will be somewhat lower in the sky.

The planet Jupiter will also be visible in November and December about 30 degrees above the horizon in the south-southwest.

Discussion

Compare the data you have collected with others in your class. Can you come up with any rule or conclusion about the motion of the moon from day to day? from hour to hour?

Star ____________________

Date:					
Time:					
Angle between star and moon:	1				
	2				
	3				
	Mean				
Altitude of moon:	1				
	2				
	3				
	Mean				

Planet ____________________

Date:					
Time:					
Angle between planet and moon:	1				
	2				
	3				
	Mean				
Altitude of moon:	1				
	2				
	3				
	Mean				

Going Further

1. If the moon is near Venus in the night sky, compare the position of the moon relative to Venus from night to night.
2. Sketch the phases of the moon alongside your other measurements. What pattern can you observe?
3. If you measure the altitude of the moon as well, you can make a simple map showing how far the moon moves each night relative to the horizon. The angle between the moon and the bright star tells you how far the moon has moved relative to the bright star (which would be a fixed reference point on your map), and its altitude tells you how far it is above the horizon. When you draw the moon on your map, be sure to include how it looks. How far does the moon appear to move each night?

This *Doing Science* was developed by **AAAS** and the **National Air and Space Museum, Smithsonian Institution**
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THE BIG DIPPER AND POLARIS

Introduction

The Big Dipper is easy to spot because of its distinctive shape. You can use the Big Dipper to find Polaris, also known as the North Star. Four stars form the bowl of the Big Dipper. The two stars farthest from the handle point to Polaris, no matter what the position of the Big Dipper in the sky. Move your eye along the direction of the two pointer stars. The first bright star you see is Polaris.

Have you ever observed how the Big Dipper changes its position from hour to hour, or from night to night? And what about Polaris—does it change its position in the sky from hour to hour, or from night to night? You can use your astrolabe to study the motions of the Big Dipper and Polaris.

Science Themes

astronomy
geometry

Science Skills

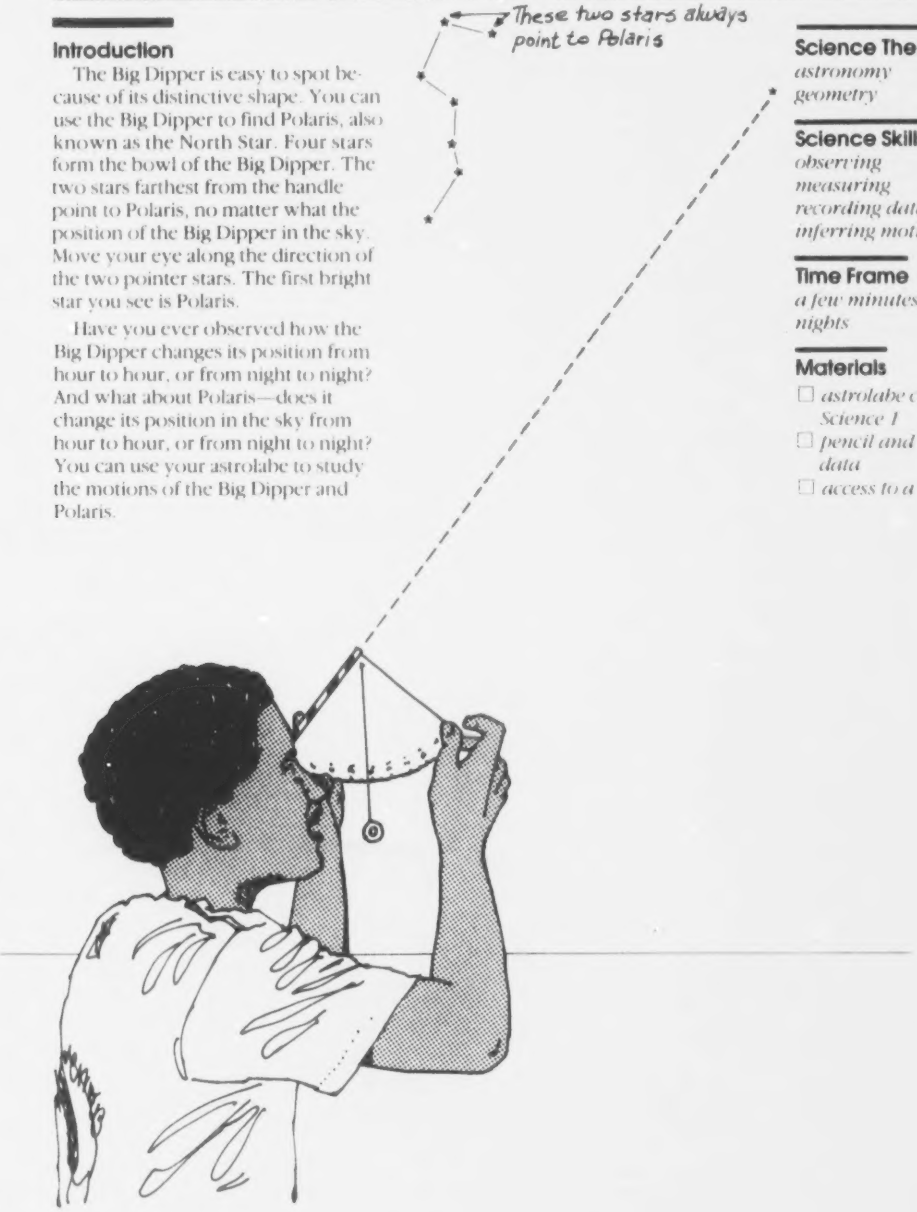
observing
measuring
recording data
inferring motion

Time Frame

a few minutes each hour over several nights

Materials

- ☐ *astrolabe constructed in Doing Science 1*
- ☐ *pencil and notebook for recording data*
- ☐ *access to a wrist watch or clock*


These two stars always point to Polaris

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The Activity

1. *From hour to hour.* On a clear evening, use your astrolabe to measure the altitude of one of the stars in the Big Dipper at 8 p.m., 9 p.m. and 10 p.m.

Each time make three measurements. Record each measurement and calculate the mean.

Do the same for Polaris.

2. *From day to day.* Measure the altitude of the star in the Big Dipper at 8 p.m. each night for about a week.

Each time make three measurements. Record each measurement and calculate the mean.

Do the same for Polaris.

3. Arrange your data into a table.

Discussion

What conclusions can you make about how the Big Dipper changes its position from hour to hour? from day to day? Does your data agree with others in your class?

What conclusions can you make about the motion of Polaris?

Going Further

Look up the latitude of your town or city in an atlas. Compare this number with your altitude measurements for Polaris. If you travelled to Fairbanks, Alaska and measured the altitude of Polaris with your astrolabe, do you think you would get the same number? What if you went to Miami, Florida and measured the altitude of Polaris?

Circle the star whose altitude you measure

Date: ________		8 p.m.	9 p.m.	10 p.m.
* * * * * * *	Altitude 1.			
	2.			
	3.			
	Mean			
Polaris	Altitude 1.			
	2.			
	3.			
	Mean			

From hour-to-hour

Circle the star whose altitude you measure

Date	* * * * * * * Altitude at 8 p.m.		Altitude of Polaris at 8 p.m.	
	1. ____ 2. ____ 3. ____	Mean	1. ____ 2. ____ 3. ____	Mean
	1. ____ 2. ____ 3. ____	Mean	1. ____ 2. ____ 3. ____	Mean
	1. ____ 2. ____ 3. ____	Mean	1. ____ 2. ____ 3. ____	Mean
	1. ____ 2. ____ 3. ____	Mean	1. ____ 2. ____ 3. ____	Mean
	1. ____ 2. ____ 3. ____	Mean	1. ____ 2. ____ 3. ____	Mean
	1. ____ 2. ____ 3. ____	Mean	1. ____ 2. ____ 3. ____	Mean
	1. ____ 2. ____ 3. ____	Mean	1. ____ 2. ____ 3. ____	Mean

From day-to-day

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PARALLAX—HOW FAR IS IT?

ACTIVITY J-2

GRADE LEVEL: 8-12

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What's This Activity About?

When we look at stars in the sky, we can measure how they differ in brightness, but we cannot easily tell how far away stars are. Astronomers can use the Earth's motion around the Sun to help measure distances to stars by using *parallax*, a process similar to the way surveyors measure distances on Earth. Parallax is the apparent change in position of a nearby object because of a change in view. When you hold out your hand and view it with your left eye only, then with your right eye, your hand seems to shift relative to the distant background. Astronomers can measure this apparent shift in the sky with careful observations made over six months as the Earth orbits the Sun.

This is a challenging activity for any grade level, but the geometrical method of determining stellar distances via parallax is crucial for our understanding of the scale of the cosmos and of stellar evolution. The math for this activity is not difficult, but success depends upon good measurement and recording skills. Trigonometry is not required but can be used for later grades if desired.

What Will Students Do?

Students measure distances to various targets inside and outside the classroom and check their measurements with observations of parallax.

Tips and Suggestions

This activity could be used before or during a unit about stars, to help students understand how we know stellar luminosities, radii, and masses.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Angles	Measuring	Scale
Ratios	Recording	
	Calculating	

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Parallax—How Far Is it?

How far away is that flagpole? Set your sights on a very distant reference object and compare where the flagpole is in relation to that distant reference object. Then move to a new observing position and again compare where the flagpole is in relation to the distant reference object. The apparent change in position is the flagpole's parallax. In this activity, your students use a parallax angle measuring device to determine distance.

Materials

- ☐ Parallax Angle Measurer cutout sheet—scale piece (1/student + 2 for the teacher; photocopy master on page 35)
- ☐ Distance Measuring worksheet (1/student; master on page 36)
- ☐ 6 to 10 sheets of construction paper, $8^{1}/_{2}$" x 11", various colors
- ☐ Ruler or 8-1/2" x 11" sheet of paper (1/student)
- ☐ Scissors (1/student)
- ☐ Push pin (1/student)
- ☐ A bit of wine cork, eraser, wood, styrofoam or other soft material, at least 1 cm thick, for a push pin to stick into (1/student)
- ☐ Five or six tape measures
- ☐ 2–3 rolls of tape
- ☐ Optional: Overhead projector and 3 sheets of acetate.
- ☐ Optional: Two or three tape measures

Before Class

1. Make one photocopy each of "Angle Measurer" cutout sheet and "Distance Measuring" worksheet for each student. The angle measurer will work best if you photocopy onto cardstock, though regular paper works adequately.

2. Cut bits of material that the push pin can be stuck into. Wine corks, big pencil erasers, or styrofoam can be sliced up with a sharp kitchen knife into pieces about 1 cm thick.

3. Assemble a demonstration angle measurer yourself, following the instructions in step 1 (below).

4. Make 6 to 10 cardboard targets out of different colored construction paper. The targets can be stick people figures, cones, or other shapes. Making each one a different color will allow students to distinguish them easily. Place the targets among the students' desks so that the targets extend well above the height of the desks, 30 cm (a foot) or so. The targets may be taped onto desks or hung from the ceiling.

5. Optional: Photocopy the cut-out sheet and the worksheet onto clear acetate for pointing out parts on an overhead projector.

In Class

1. Tell your students that they are each going to make a parallax angle measuring tool. Hand out the cut-out sheets and scissors. Explain the following steps (pointing out parts on an overhead projector if you wish):

   a. Cut out both pieces along the dashed lines.

   b. Fold up all the arrows along the dotted lines: the **reference** arrow on the scale piece, and the **target** and **eye** arrows on the pointer piece. A ruler is helpful here.

   c. Stick a pushpin through the "Pushpin" cross marks on the Pointer piece, the Scale piece, and then into the cork. The completed Angle Measurer should appear as in the figure on the cutout sheet and as your demonstration model. The pointer piece should be able to sweep along the angles of the scale piece.

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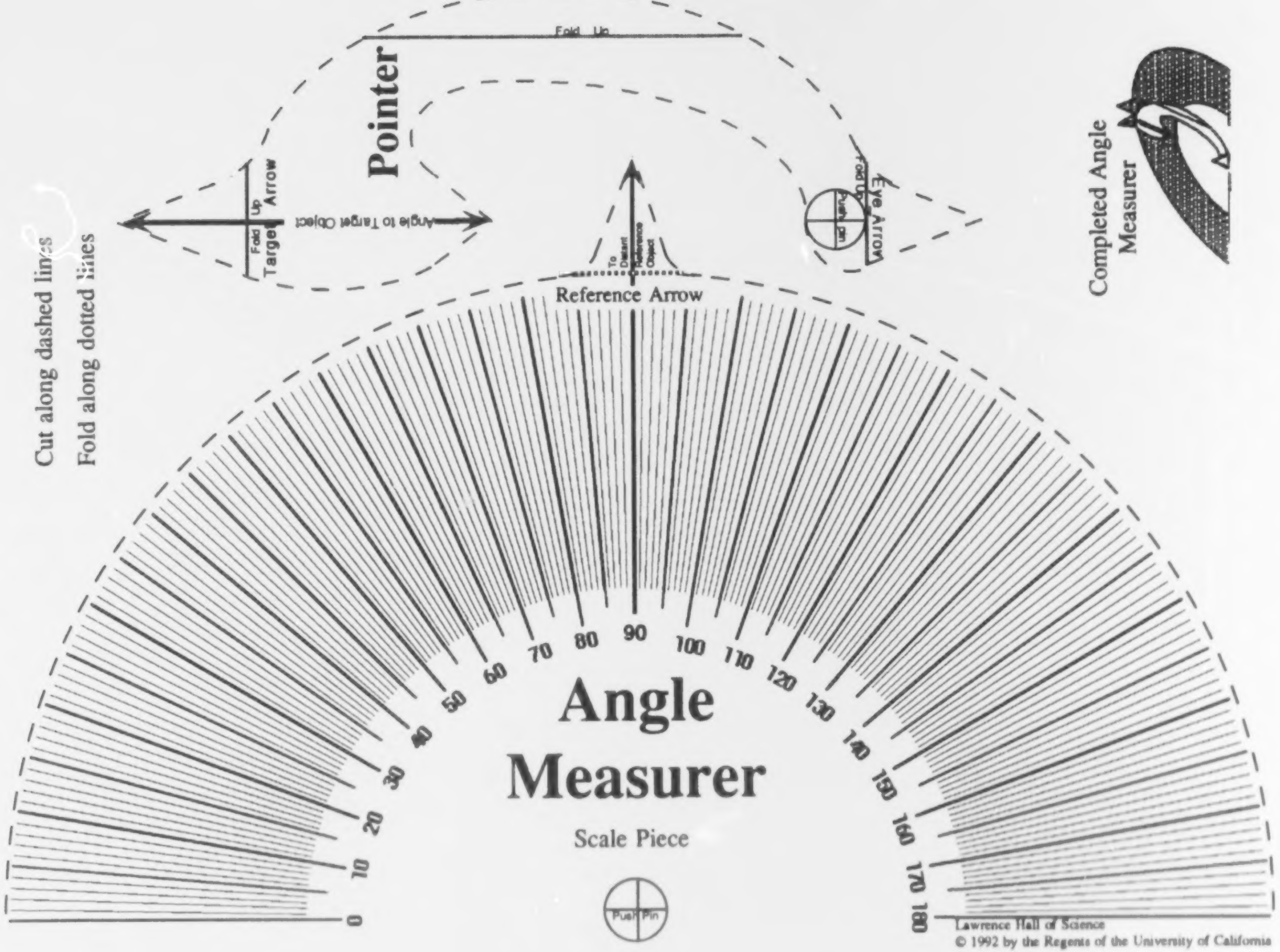
Cut along dashed lines

Fold along dotted lines


Pointer
Fold Up
Fold Up Target Arrow
Angle to Target Object
Reference Arrow
To Distant Reference Object
Fold Up
Eye Arrow
Push Pin
Completed Angle Measurer
Angle Measurer
Scale Piece
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
Push Pin

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Distance Measuring

1

Target Angle 1

Target Angle 2 —

= Parallax Angle

2

Parallax Angle	Distance in "Baselines"
1°	57.3
2°	28.6
3°	19.1
4°	14.3
5°	11.4
6°	9.5
7°	8.1
8°	7.1
9°	6.3
10°	5.7
11°	5.1
12°	4.7
13°	4.3
14°	4.0
15°	3.7
16°	3.5
17°	3.3
18°	3.1
19°	2.9
20°	2.7

Accuracy decreases with larger angles.

3

Number of Baselines

Length of Baseline ×

= Distance to Object

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2. Explain that each student is going to measure the distance from his or her desk to one of the colored targets in the room. A distant reference point will be the vertical line formed by the corner of the room farthest from the student. Ask each student to select a colored target object that is not too far from them, but in the general direction of the corner of the room that is farthest from them.

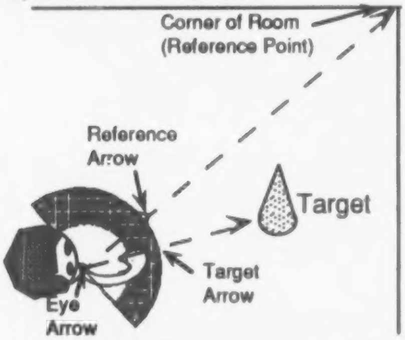
3. Have each student make a baseline by taping a ruler or sheet of paper onto their desks. The baseline should be roughly perpendicular to the direction of the target and reference objects.

4. Hand out a "Distance Measuring" worksheet to each student.

5. Tell them that they are going to measure the angle between the reference and target objects twice—one measurement at each end of their baseline. Explain the following procedure:

   (a) Put your Eye Arrow on one end of the baseline.

   (b) Line up your Eye Arrow, the Reference Arrow, and the reference point (farthest corner of the room). Emphasize that all three elements must line up as in a gunsight. Once reference corner is lined up with both the eye arrow and reference arrow, press the scale piece firmly to the desk with one hand, so that it does not move.



   (c) Now pivot the Target Arrow until it is in line with both the Eye Arrow and the colored target object, whose distance you are trying to measure. Again emphasize that all three elements must line up. Be sure you are holding the scale piece down firmly so that it does not move. Only the Pointer Piece should pivot.

   (d) Read the "Angle To Target Object" indicated on the scale and write that angle down on the worksheet in the space for "Target Angle 1."

   (e) Move your angle measurer to the other end of your baseline. Then repeat steps (b) and (c) to measure the 2nd "angle to target object." Write that angle down on the worksheet in the space marked "Target Angle 2."

6. Draw on the chalkboard as you explain that the difference between their two measured angles is the **parallax** angle. Draw the baseline and the target object and show how they form a triangle. Label Target Angle 1 and Target Angle 2. Extend the sides of the triangle and label the parallax angle as shown in Figure A. Explain that they can calculate the parallax angle by subtracting the larger angle from the smaller angle.

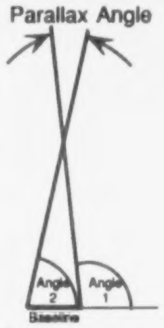


Figure A

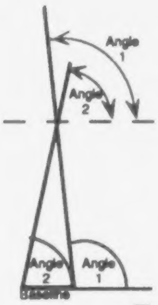


Figure B

Optional: Draw a dotted line through the target parallel to the baseline. Label angle 1 and angle 2, as shown in Figure B. Point out that Target Angle 1 is the same size as angle 1 and Target Angle 2 is the same size as angle 2. (In geometry, these are "corresponding" angles.) Sometimes it is easier for students to see why the parallax angle is the difference between angles above the dashed line than it is for them to see how the parallax relates to Target Angles drawn on the baseline.

7. Instruct your students to subtract the larger angle from the smaller angle (interchange the numbers if necessary) and write the answer in the space marked "Parallax Angle."

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8. The distance to the target is the height of the triangle and can be found in the table on the worksheet. The table lists distances in "baselines" so have your students find the distance corresponding to their parallax angle in the table and write that distance in the space marked "Distance in Baselines."
9. Have the students write in the length of the baseline in the space marked "Length of Baseline." If they used a standard ruler, the baseline is 30 cm. If they used the length of a standard sheet of paper, the baseline is 28 cm.
10. Finally, the students can calculate the distance to their target object by multiplying the "Distance in Baselines" by the "Length of the Baseline." Have them enter the answer in the space marked "Distance to Target Object." If you have tape measures, students can check their answers by direct measurement.

Going Further

Alternate Calculation Method I

You may opt for students to do a graphical calculation (draw a scale drawing):

Steps 1-6 above are the same except that in step 4, do not hand out a "Distance Worksheet." Have students record their angles on paper.

7. Use a protractor and ruler to make a scale drawing of the baseline, Target Angle 1 and Target Angle 2 with appropriate scale, e.g. 1 mm = 1 cm. Demonstrate this on an overhead transparency if possible.
8. Find the point where the angles intersect and measure the scale distance to the object..

Alternate Calculation Method II:

If your students are studying trigonometry, the Distance to the target (D) is related to the Parallax angle (α) and the Baseline (B) by the trigonometric relationship (tangent), $D = B + \tan(\alpha)$.

How Far is That Flagpole?

Your parallax Measurer can be used to find really far away distances outdoors by measuring off baselines of several meters or more.

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HELLO OUT THERE!

ACTIVITY J-3

GRADE LEVEL: 7-10

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What's This Activity About?

This activity creates a model of the speed of light, and it should be used after a scale of the solar system model to help students understand that even light speed is not infinitely fast. The concept of light-travel time (light-minutes, light-hours, light-days, or light-years as distance measurements) becomes clear as students walk between planets.

What Will Students Do?

Using a Solar System scale model, students place themselves at various distances from Earth, and then respond to a message "sent" at a fixed speed from Earth. They observe the relative amount of time for messages to travel between planets by walking at a fixed pace.

Tips and Suggestions

- When done on a large scale model across school grounds, the activity will make a deep impact on students as they see how long electromagnetic messages take to travel large distances.
- The activity asks that students walk heel-to-toe between planets to simulate the finite speed of light. Emphasize that they do not have to run, nor even walk fast—it isn't a race.
- Based on your scale model, compare how long the students take to travel between Earth and a certain planet to the time a real message would take (based on about 8 minutes to travel one Earth-Sun unit).

What Will Students Learn?

Concepts

The finite speed of light
Distance, velocity, and time

Inquiry Skills

Experimenting
Comparing
Inferring

Big Ideas

Models and Simulations

Hello Out There!

Background

Everything we see, we see because of light. We see a tree because light reflects off the tree and travels to our eyes. Light travels so fast (300 thousand km/sec!) we have trouble believing that it takes the light any amount of time to travel from the tree to our eyes. For this reason, when we see something happen, we assume that it is happening at that instant. If we go to a baseball game and see a ball being hit, we assume that the ball was hit the moment we saw it happen. But we do not assume the same thing for sound. For example, when we see a bolt of lightning off in the distance, we see the flash of light before we hear the thunder. The light from the lightning reaches us before the sound does because sound travels much more slowly than light (340 m/sec at 15° C).

All forms of light (X-ray, radio waves, microwaves, visible light) travel at the same speed—300 thousand km/sec. Why does light seem to reach us instantly? For two reasons: the distances we are familiar with are very short, and light travels a short distance very fast. When distances become great, the lag time between something happening and us seeing it happen becomes more obvious, just like with the sound of thunder after we see the lightning. For example, the light we are seeing from the Sun actually left the Sun a little more than eight minutes ago.

Stars other than the Sun are much farther away, therefore lag time is much greater. Distances to stars are often measured in light years. A light year is the *distance* that light can travel in one year. If a star is six light years away from Earth, that means that the light leaving the star takes six years to reach us. That also means that the things we are seeing happen on that star actually happened six years ago. In the same way, if there were people on a planet close to the star looking at us, they would see what happened here in 1986, not 1992. They will never be able to see anything more recent than six years in our past.

Objective

The objective of this activity is to understand the consequences of light having a finite speed.

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Procedure

This activity uses the model of the Solar System constructed in the activity "Solar System Scale." Your teacher will give you the directions for the present activity.

Questions and Conclusions

1. Did you find out what was happening on Earth the instant it happened? Why or why not?
2. What were the consequences of the message from Earth taking time to reach you?
3. How does what you learned in this activity apply to sending information to and receiving information from spacecraft by radio waves? Remember that radio waves are a form of light.

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Hello Out There!

What Is Happening?

In common experience, it is assumed that light travels over any distance instantaneously. This is because the distances we normally encounter are relatively short, and the speed of light is very great. However, light does take time to travel, and when the distances become great enough, this becomes apparent. An analogy can be made with sound, which travels more slowly than light. If the distance is great enough, there is a lag between seeing an event and hearing the sound that results from it. For example, when we see a bolt of lightning off in the distance, we see the flash of light before we hear the thunder. The light from the lightning reaches us before the sound does because sound travels much more slowly than light.

All forms of light travel at the same speed, 300,000 km/s. Radio waves, one form of light, are used to communicate with spacecraft. The signals now being received from Voyager take hours to reach Earth. The star Sirius (the brightest star as seen from Earth except for the Sun) is 9 ly away. This means that the light now reaching Earth from Sirius left the star nine years ago. If there were people on Sirius watching Earth, they would now be seeing what happened here nine years ago. All this is because light takes time to travel.

This activity is designed to help students understand that light does have a finite speed and that this has consequences for us. In order to grasp the meaning of the activity, it is important for students to understand that light acts as a messenger in the same way that a person can. Both transfer information from one point to another. How quickly the information is transferred depends on the speed of the messenger, whether the messenger is a person or light.

Important Points for Students to Understand

◊ Light takes time to travel.

◊ Distances must be very great in order for the consequences of the speed of light to become apparent.

◊ A fundamental consequence of the finite speed of light is that we always see a star's past, not its present.

Materials

For each student:

◊ a piece of candy or other treat (make sure no one is allergic to it)

Vocabulary

Speed of light: According to Albert Einstein's theory of relativity, the speed of light is constant: 299,800,000 m/s (usually rounded to 300,000,000 m/s for purposes of calculation). In this book, 300,000 km/s is used for comprehension and comparison.

Speed of sound: This varies depending upon the conditions through which sound moves, such as the density and the temperature of the medium. For the purpose of this activity, the speed of sound at 15° C in air is 340 m/s.

Radio wave: Like visible light, this is a form of electromagnetic radiation ranging in wavelength from 1 cm to 100 km. Radio waves are low in energy and are used for, among other things, communication with spacecraft. Like all electromagnetic radiation, radio waves travel at the speed of light.

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Time Management

This activity will take much less than one class period. It may be possible to do it on the same day as day two of the activity "Solar System Scale."

Preparation

This activity should be done in conjunction with Activity 3, "Solar System Scale," or a similar activity on the Solar System. It also assumes that the students are familiar with a light year, as described in Activity 2, "Time Traveler." Assuming some kind of scale model of the Solar System has been built (for example, the one in Activity 3, "Solar System Scale,") there is very little preparation required other than buying the candy for the students. Time may be saved by dividing the students into their planet groups and designating the messenger prior to the activity.

For additional information, refer to Reading 2, "What is a Light Year?" and Reading 3, "Hubble Space Telescope."

Instructions

1. Select a volunteer or designate a student to be the "electromagnetic messenger."
2. Divide the class into three or four groups and position one group at each of the following planets in your scale model of the Solar System: Mars, Saturn, Uranus, and/or Pluto. Have the students face *away* from Earth.
3. Tell the class that you (the teacher) will be on Earth sending out radio messages into the solar system via the electromagnetic messenger.
4. The electromagnetic messenger will walk heel-to-toe. The students must also walk heel-to-toe when they travel.
5. Since sound cannot travel in outer space, there must be no talking.
6. Send the messenger out into the solar system with a card for each planet that is inhabited. Each card should read, "Mr./Ms. _________ is on Earth handing out a limited amount of candy to hungry astronauts. Go to Earth if you want some candy. Remember, you must walk heel-to-toe, and NO TALKING!" Students must read the message silently.
7. As students arrive, hand each one a piece of candy inconspicuously. When the last group arrives, tease them that you

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have run out of candy, but don't forget to give it to them later.

Suggestions for Further Study

Encourage students to come up with a more elaborate skit to demonstrate consequences of light having a finite speed. This would be an excellent opportunity for students to work in cooperative learning groups. Their group work could be an assessment technique to evaluate whether or not the students grasp the concept.

Have students investigate how astronomers deal with the fact that what they see from stars happened years ago. How do they solve the problem of never being able to see what is happening in a star's present?

Suggestions for Interdisciplinary Reading and Study

Light is electromagnetic radiation. It includes infrared, visible, ultraviolet, and X-rays, and all travel at exactly the same speed. The various forms of light have both harmful and helpful effects. X-rays revolutionized diagnostic medicine. Too much X-ray radiation, however, has been shown to be harmful. Students can investigate the uses of all the different forms of light and their effects on humans.

Various forms of light provide valuable information for astronomers about the Universe. The idea behind the Hubble Space Telescope was to place a device to gather light (of both visible and ultraviolet wavelengths) above the atmosphere where it could get an unobstructed picture of these types of light from objects in space. When light travels through the atmosphere, it can be refracted, reflected, or absorbed, making it difficult to get an accurate picture of the light from planets and stars with a ground-based telescope. In orbit around Earth, Hubble receives light that is unaffected by Earth's atmosphere. See Reading 3, "Hubble Space Telescope," for a more detailed description.

The idea of seeing a star's past brings up the topic of time travel. In a sense, we are going back in time when we observe any star because we see the star's past as though it were the present. Time travel is a popular theme in science fiction. Madeleine L'Engle's *A Wrinkle in Time* is an account of travelling through time between the planets. The poem "Messages" by Myra Cohn Livingston at the beginning of this activity describes some of the

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different messages we receive from space. Encourage students to investigate the phrases "pulsing beats from distant neutron stars" and "radio blackouts from a solar flare" from the poem.

A writing activity that integrates astronomy and geology could be inspired by the following scenario. "A huge mirror has been discovered fifty million light years from Earth in space. With your telescope, you can focus on the mirror and see a reflection of Earth. Your telescope is so powerful that you can make out as much detail as a small river on Earth. Write an essay that describes what you would see happening on Earth and when in Earth's past these things would have happened." (This would be 100 million years ago, as light reflected from the Earth had to travel 50 million years to reach the mirror, then another 50 million to reach the telescope.)

While not apparent in this activity, light can be modeled as a wave (though it also behaves in some ways like a particle). Waves have relevance in other areas of Earth science besides astronomy. Some geologists study waves that travel through our planet, particularly those that are the result of earthquakes. It is these waves that cause damage from earthquakes. Sound is another example of a wave. Oceanographers often study ocean waves. These waves have properties in common with light waves. Encourage students to compare and contrast these different waves.

Answers to Questions for Students

1. No. Because it took time for the messenger to reach each planet. He or she did not get there instantaneously.
2. All students got the message "late." For the farthest students, this meant not getting to Earth before the candy ran out.
3. Any information we send or receive takes time to arrive even at the speed of light. For example, if NASA wants the Voyager spacecraft to make a turn at a certain time, the message must actually be sent hours before that time so that the message will have time to travel.

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LIGHT AND COLOR—ACTIVITIES FROM THE FOSTER PROJECT

ACTIVITY J-4

GRADE LEVEL: 6-12

Source: Reprinted by permission from Flight Opportunities for Science Teacher EnRichment (FOSTER), SETI Institute, 2035 Landings Drive, Mountain View, CA 94043.
Contact: Edna DeVore.

What's This Activity About?

This is an integrated set of activities about light, spectra, color, and astronomical images, based on the Lawrence Hall of Science GEMS guide, *Color Analyzers*. One of the strongest parts of this activity has students observe astronomical images (gaseous emission nebulae, planetary nebulae, and star clusters) through different color filters, which is exactly the same process astronomers follow.

What Will Students Do?

Students investigate color filters, diffraction-grating spectra and absorption of colors. Students use color filters to view astronomical images, observing different features that are visible with different colors of light.

Tips and Suggestions

- Many of the special materials required for this activity are provided with the GEMS guide, but more powerful holographic diffraction gratings (with more lines per inch) should be used if possible to spread the light spectrum out even more. A good source for such a grating is Learning Technologies, Inc. (See the address listing in the *Resources and Bibliographies* section of this notebook.)
- The activity describes the materials needed and where to get them.

What Will Students Learn?

Concepts

The electromagnetic spectrum
Wavelength and color
Spectra

Inquiry Skills

Observing Systematically
Experimenting
Using Instruments
Explaining

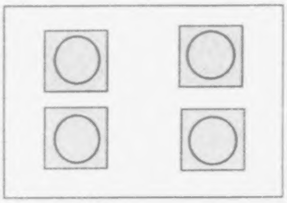
Big Ideas

Energy
Matter
Interactions

Light and Color
Activities from the FOSTER Project

Activities—

Color Analyzers—Color analyzers allow students to experiment with colored filters to learn about light and color. For students to make a "color analyzer," you need the following:



Color Analyzer

-one 3" x 5" card with pre-drilled holes 1/2" to 1" in diameter

-one set of filters—red, green, blue, yellow

-transparent tape

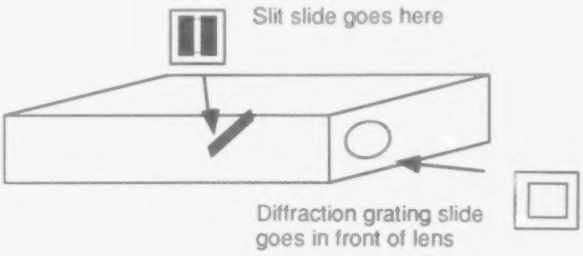
The holes need to be wider apart than the spacing of human eyes so that we don't get into distractions about 3-D glasses. (Make those another time.) Cut the color filters into squares a little larger than the holes. Give each student a card, one square of each filter, and have the students tape the filters over the holes. When they use the color analyzer, they will see only the light transmitted by the filter—red through the red filter, and so on.

Secret Messages—Secret messages can be created with crayons or felt pens. The messages can be "decoded" using a color analyzer. Students enjoy creating and reading messages, and this leads them to an understanding of how filters work and how light is transmitted and absorbed. The activities are drawn from *Color Analyzers*, a GEMS Guide from Lawrence Hall of Science (see the source list).

Color in the Environment—Using the color analyzers, have students look at clothing, posters, and other colored objects in the area. They will observe changes as they use different filters. Ask them to record their observations, and explain what they observed.

Exploring the Visible Spectrum—The purpose of these activities is for students to understand that visible (white) light is a combination of its component colors, and some of the ways visible light is studied in astronomy.

How To Project A Large And Bright Spectrum In The Classroom: Slide projector method—
You need the following:



-a slide projector (and source of power)

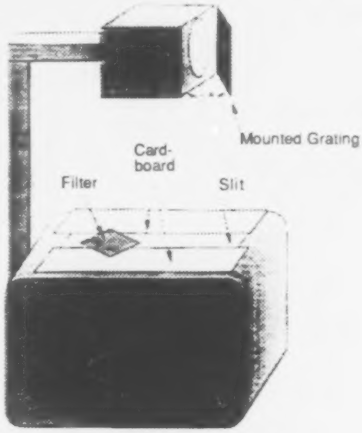
-a slide with narrow slit

-a diffraction grating

-masking or electrical tape

-white wall or screen

To make a visible light spectrum, plug in the projector, and turn on the lamp. Place the silt slide into the slide projector so that the slit makes a white vertical line on the screen or wall. Focus the projector. Now, place the diffraction grating slide over the front of the lens. (You may need to rotate the diffraction grating slide to get the spectrum on the wall, rather than the ceiling and floor.) The visible spectrum will appear on both sides of the white line on the screen or wall. You may wish to move the projector so that one part of the spectrum appears on the screen or wall. *Note: this works best in a very dark room.*



Overhead Projector Method—
You need the following

- an overhead projector (and a source of power)
- two pieces of 8" x 10" construction paper
- large diffraction grating—4" to 5" square
- white wall or screen

To make a visible light spectrum, plug in the projector, and turn on the lamp. Place the construction paper on the overhead so that there is a slit about 1" wide on the base plate of the projector. Focus the projector. Place the diffraction grating in front of the upper lens, and rotate the grating until the spectrum appear on both sides of the projected slit on the wall or screen. You may wish to move the projector so that one part of the spectrum appears on the screen or wall. *Note: this works best in a very dark room.*

How To Observe The Spectrum With A Diffraction Grating, The Light Bulb Method—
Individual students may observe the spectrum directly with a diffraction grating slide, or a piece of diffraction grating, as described in the GEMS Guide, *Color Analyzers*. In this method, you need:

- one diffraction grating per student
- a bright, clear (unfrosted) single filament light bulb—75 to 200 watts—available at hardware stores.
- lamp socket with clip base (or a table lamp without a shade) so that the bulb can be seen by all students

Darken the room, distribute the diffraction gratings, and turn on the lamp. Direct students to look through the grating at the lamp and observe the colors on either side of the lamp. Students will need to rotate the grating to place the visible spectrum on either side of the lamp. Caution your students not to touch the diffraction grating. Finger oils clog up the grooves in the grating and then it does not work well. *Note: this works best in a dark room.*

Coloring the Spectrum—
Students need crayons or colored pencils, white paper, and a spectrum to observe in a darkened room. With a projected spectrum, or the light-bulb method (see above), allow students to observe the visible spectrum. Using crayons or colored pencils, have students color the spectrum on paper. They may record six, rather than seven colors. The human eye does not separate indigo and violet well. (Some physicists argue that there are only six main colors in the visible spectrum, and that seven colors were included by Isaac Newton for mystical reasons!) The students should note that the colors are not separated by dark spaces, but form a continuous spectrum.

Color Absorption—Why are apples red and why is grass green?
For this activity, you need the following materials:

- 8" x 11" pieces of blue, green, yellow, and red felt mounted on stiff paper like file folders
- a projected spectrum (see above)

The principle here is simple. A piece of red felt will absorb all colors but red, which reflects to our eyes. In blue light, a true red will look black—it absorbs all of the blue, and there are no other colors to reflect to our eyes! Usually, each piece of felt will reflect several colors. Have students examine the different pieces of felt in different parts of the spectrum, and record the results for each piece. (Yellow is usually a surprise!) *Reinforce the concept that the color of the felt is the color of light reflected to our eyes,* not the color absorbed by the felt. To extend this activity, ask students, "Why are apples red, and grass green?" Red apples mostly reflect red light, and green grass (and green apples) mostly reflect green light.

Clothing: Have students with brightly colored clothing walk slowly through the spectrum. Their clothing will reflect and absorb colors just like the felt. On some prints, designs appear and disappear. You may wish to purchase brightly colored pieces of cloth for demonstrations—mixed purple, red, blue, green, and yellow prints work best.

Red Stars and Blue Stars: If you have a room which can be totally darkened, illuminate it with red light bulbs—light from a "red star." Pass around a piece of printed cloth, and have students try to determine the colors on the cloth, then turn on the room (white) lights, and discuss what they observed. If you wish to get more complex, switch from red to blue lights before turning on the white lights. Comparing the "red starlight" and the "blue starlight" can be very thought provoking. What would happen if our star gave off mostly red light? blue light? What colors would we use, and what colors would we not use? What is the main (peak) color for our Sun? What color do we see best? For further information, see PASS Series, Colors *and Space, Vol. 8,* in the source list.

Can You Touch a Star? Analyzing Astronomical Photography—

The color analyzer allows us to analyze photographs of astronomical objects. Slides and posters may be obtained from a variety of sources, including the Astronomical Society of the Pacific and NASA Teacher Resource Centers, and NASA CORE. Colored slides of planets, nebulae, and star fields work well. Project the slide in a darkened room, and have the students look at the image with the color analyzer. Discuss the changes visible, especially using the green and red filters. Alternatively, simply place a large piece of the red, green or blue filter in front of the projection lens for the whole class to observe the changes.

Questions to ask about planet and nebula photos: What details are highlighted? Disappear? What does this tell us about the light coming from various parts of the planet/nebula?

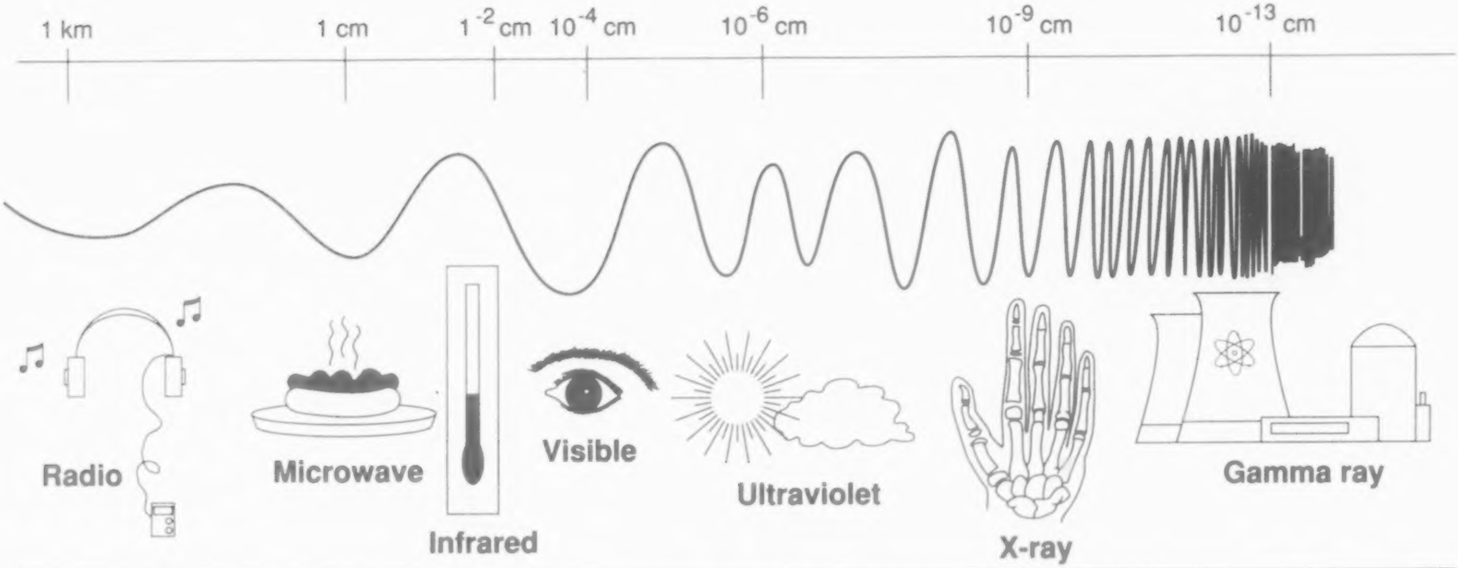
Questions to ask about star fields: (Without filters first) Can you see any differences between the stars? (Brightness, color, position.) Hold a red filter in front of the projector. What stars disappear? What does this tell you about the light from those stars? (It is mostly blue, and blocked by the red filter.) Hold up the blue filter, and repeat the questions. Stars vary considerably in terms of color. All stars emit a continuous spectrum, but have a peak color (frequency or wavelength) which is determined by their surface temperature. Stars with low surface temperatures give off mostly red light, while hotter stars emit mostly in the blue part of the spectrum. Middle-sized stars like the sun emit mostly yellow light. Have students identify stars that are predominantly one color.

Background Information—

Electromagnetic Radiation

Stars emit a broad spectrum of electromagnetic energy, ranging from low frequency radio waves to incredibly high frequency x-rays and gamma rays. Frequency is the number of waves to pass a given point, or "cycles per second." Electromagnetic energy is described by "wavelength" as well. Radio waves have long wave lengths—(.1 m to 100 km)—and gamma rays have incredibly short wave lengths—(10^{-12} m to 10^{-15}m). See the diagram on the following page.

The Electromagnetic Spectrum


1 km
1 cm
1^{-2} cm
10^{-4} cm
10^{-6} cm
10^{-9} cm
10^{-13} cm
Radio
Microwave
Infrared
Visible
Ultraviolet
X-ray
Gamma ray

All forms of electromagnetic energy travel at 299,792 kilometers per second (186,000 miles per second)—the speed of light! The relationship between frequency, wavelength and the speed of light is:

speed of light = wavelength times frequency or $c = \lambda\nu$

All forms of electromagnetic radiation together are represented by a continuous band of wavelengths or frequencies called the electromagnetic spectrum. The divisions are somewhat artificial, but represent regions of the continuous spectrum.

Visible Light: Light is visible electromagnetic radiation—the portion of the spectrum you detect with your eyes. Other portions of the spectrum require other types of "detectors." What we call "white light" is really the combination of all of the visible spectrum colors: red, orange, yellow green blue, indigo and violet. (The order is remembered by Roy G. Biv.) Under ordinary conditions, we do not see the colors separately. Natural phenomena, like water droplets in rainbows and the spray of waterfalls and sprinklers, break up the white light into its component colors. Artificially, we can break up white light with a prism (fairly expensive) or a diffraction grating (much less expensive).

Spectroscopes: Astronomers (and other scientists) use an instruments called a spectroscopes to study electromagnetic radiation. A spectroscope uses a prism or diffraction grating to spread light (and other electromagnetic radiation) into a spectrum. Attached to a telescope, a spectroscope allows astronomers to analyze the light (and other electromagnetic radiation) from all the objects we can observe in the universe—planets, moons, comets, stars, nebulae, dust clouds, and galaxies. The spectra of these objects can reveal the temperature, chemical composition, direction and speed of travel, rotation rate, and presence of unseen companions.

Color Filters—When we see a red apple, we see the colors reflected from the surface—all other colors are absorbed by the apple. When we look through a colored filter, we see the only colors that are transmitted through the filter—all other colors are absorbed by the filter. Color filters may be purchased from theatrical supply or art supply stores. (Science supply catalogs sell kits, but they are more expensive!) See the source list for the details of what to buy. Colored cellophane and colored transparencies will not work very well, but are nice to compare with the filters.

In theory, a "true" filter will only transmit light of a particular color (wavelength or frequency) through to your eyes. So, a red filter should only let red light through. You can test the filter setting up a projected spectrum, and placing the filter just in front of the diffraction grating. On a white screen, only red should show up if you have a good filter. (All of the other colors are absorbed.)

Now for reality—true filters are nearly impossible to obtain. Usually, the red filters work the best, and the others let through more colors.

NOTE: Students may ask if the atmosphere acts as a filter. For instance, the sky looks blue. This is due to "Rayleigh Scattering" not simple absorption. You may want to look up this term in an encyclopedia.

Resource List—

Color Analyzers, GEMS Guide, and ***Colors and Space, Volume 8***, PASS Series
from Eureka, Lawrence Hall of Science, UC Berkeley, Berkeley, CA 95720—(510) 642-1016

Light, Color and Their Uses, a teacher manual, and a video tape, ***Optics—Making Light Work***
ASTRO 1—Seeing in a New Light—A Teacher's Guide with Activities
from NASA Marshall Space Flight Center, Public Affairs Office, CA20, Huntsville, AL 35812
(205) 544-6548, and regional NASA Teacher Resource Centers

Project STAR—The Universe in Your Hands, a high-school astronomy curriculum
from Kendall Hunt Publishing, P.O. Box 539, Dubuque, Iowa 52004-0539

"Light," ***Kids Discover***, October, 1993. Kids Discover, 150 %th Ave., New York, NY 10010, (212) 242-5133

Gardner, Robert. ***Investigate and Discover Light***, Julian Messnet, 1991.

Jennings, Terry. ***Light and Color***, Children's Press, Chicago. 1982

Malin, David. **"A Universe of Color,"** ***Scientific American***, Aug., 1993, pp. 72-77.

Sadler, Philip. **"Projecting Spectra for Classroom Investigations,"** ***The Physics Teacher***, Oct., 1991, pp. 423-427.

Diffraction Grating Materials, Slides, Spectroscopes, and Overhead Projector Kits—

from Learning Technologies, Inc., 59 Walden St. Cambridge, MA 02140—(800) 537-8703
from Arbor Scientific, P. O. Box 2750, Ann Arbor, MI 48106-2750—800-367-6695
spectrum cardboard glasses from Rainbow Symphony, 6860 Canby Ave. #120, Reseda, CA 91335—800-821-5122

Color Filters From Theater Lighting Supply Stores—

-Red: "medium red, ROSCOLUX #27"
-Green: "dark yellow green, ROSCOLUX #90"
-Blue: "primary blue, ROSCOLUX #80"
-Yellow: "canary, ROSCOLUX #312"

Note: other manufacturers of filters will have different code numbers. Tell the store personnel that you are seeking "pure" color filters for science experiments, and they should be able to help you select appropriate filters.

Astronomical Slides, Posters, Software, and other Publications—

Astronomical Society of the Pacific, 390 Ashton Ave., San Francisco, CA 94112
Hansen Planetarium Publications, 1098 South 200 West, Salt Lake City, UT 94101-3003
Finley-Holiday Films, 12607 E. Philadelphia St., Whittier, CA 90601
NASA Jet Propulsion Laboratories, Teacher Resource Center, JPL Educational Outreach, 4800 Oak Grove Drive, Mail Code CS-530, Pasadena, CA 91109 (818) 354-6916
NASA Ames-Dryden Flight Research Facility, Public Affairs Office (TRL.42), Teacher Resource Center Edwards AFB, CA 93523 (805) 258-3456
NASA Ames Research Center, Teacher Resource Center, Mail Stop T-025, Moffett Field, CA 94035-1000 (415) 604-3574
NASA Central Operation of Resources for Educators (CORE), Lorain County JVS, 15181 Route 58 South, Oberlin, OH 44074
Science Graphics, P. O. Box 7516, Bend, OR 97708

Acknowledgment—

These activities have been adapted for use in a NASA Astrophysics Division program, Flight Opportunities for Science Teacher EnRichment (FOSTER). FOSTER teachers attend summer workshops at Ames Research Center to prepare to fly aboard NASA's Kuiper Airborne Observatory. The activities derive from the excellent work done by the Astronomy and Physics Education group at Lawrence Hall of Science, UC Berkeley, and from Project STAR and Project SPICA at the Harvard Smithsonian Center for Astrophysics. FOSTER is a NASA Astrophysics Division program; all of the other projects have been largely supported by various grants from the National Science Foundation.

For further information on FOSTER, contact

Edna DeVore, Education Coordinator
FOSTER Project
SETI Institute
2035 Landings Drive
Mountain View, CA 94043

voice—(415) 961-6633
fax—(415) 961-7099
internet—edna_devore@seti-inst.edu

SEEING THE INVISIBLE: STUDYING INFRARED AND ULTRAVIOLET

ACTIVITY J-5

GRADE LEVEL: 7-10

Source: Reprinted from *Astro-1 Teacher's Guide: Seeing in a New Light.* Produced by NASA, Jan. 1990. Contact Educational Affairs Division, Code XE, NASA, Washington, DC 20277-2028.

What's This Activity About?

Most of the electromagnetic spectrum is invisible to our eyes, but these simple experiments elegantly show the existence of longer-wavelength *infrared* radiation, and shorter-wavelength *ultraviolet* light. Detecting the ultraviolet light requires ammonia and blueprint paper; some teachers may prefer to do this part of the activity as a demonstration.

What Will Students Do?

To study infrared light, students observe a thermometer placed at the edge of a band of light created by a prism (or diffraction grating) and notice a temperature increase even though no "visible" light falls on the thermometer.

To study ultraviolet light, students observe as sunlight is passed through a prism, and its spectrum is spread onto blueprint paper. Students mark the paper where the visible spectrum appears. Both visible and (unseen) ultraviolet light cause a chemical reaction in the paper. Students hold the blueprint paper near ammonia fumes to "develp" the paper and reveal the reaction caused by the UV light.

Tips and Suggestions

- The infrared activity can be extended with calculations of the approximate wavelengths of infrared light close to the red end of the spectrum (known as "near IR").
- Students in advanced grades also can measure the angle of deviation of IR light though the prism or grating, or investigate filters and their effects on the IR beam.
- For the ultraviolet activity if pure ammonia and blueprint paper are not available, you can use an ammonia-rich cleaning solution and "sun paper" to make solar prints of leaves and flowers (available in nature stores).

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
The electromagnetic spectrum	Observing	Energy
Light Energy	Inferring	
Chemical reactions to light	Applying	

Seeing the Invisible

Concept 5
Radiation exists above and below the visible portion of the electromagnetic spectrum.

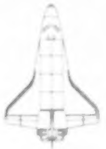
Objective
Students see evidence of the existence of radiant energy above and below the visible spectrum.

Background

While creating a spectrum is enjoyable, the exciting part is still to come: exploring the spectrum that is invisible.

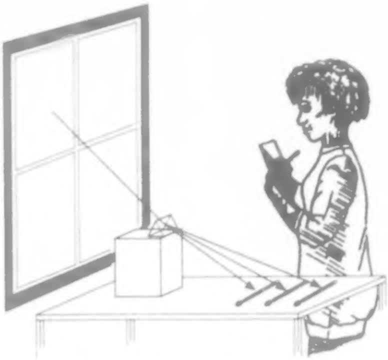
Have you ever had X-rays taken? What did they look like? What could you see? Did you see the X-rays coming out of the machine? How did you know they were there?

X-rays are part of the spectrum but are invisible. Today, you will prove the existence of invisible radiation. Remember, radiation means energy. These invisible rays are beyond both the red and violet ends of the visible spectrum and were discovered when Johann Ritter proved the existence of **ultraviolet rays** and William Herschel did the same with **infrared radiation**. These activities use almost exactly the same methods that were used in the 1800s when these discoveries were made.



Activity 1: Herschel's Experiment

To demonstrate the existence of infrared radiation, duplicate Herschel's experiment.



Materials Needed

- prism
- light source
- three weather thermometers
- pencil and paper

Step 1: Allow the three thermometers to register the temperature of the air where the experiment will be done — about 5 minutes. Take careful note of the temperatures.

Step 2: Create a spectrum using sunlight as the light source. (See Concept 1.)

Step 3: Place thermometers at several points in the spectrum: one in the violet range, one in the center, and one just barely beyond the red end. Leave the thermometers in the spectrum for at least 5 minutes, moving carefully as the sunlight moves the spectrum. Temperature changes may be very slight, so observe carefully.

Questions

1. What were the final readings on each of the three thermometers?
2. Why would there be an increase in temperature beyond the red end of the spectrum?
3. What does this tell us about what exists beyond the visible red?

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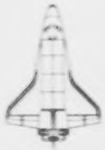
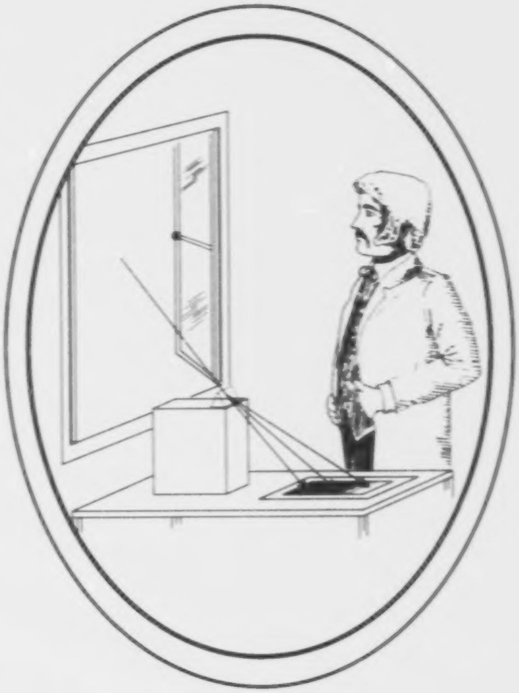


Activity 2: Ritter's Experiment

To demonstrate the existence of ultraviolet radiation, duplicate Ritter's experiment. In 1801, Johann Ritter performed an experiment using paper treated with silver chloride, which decomposes in the presence of light. He found that the silver chloride deteriorated even more rapidly when exposed to the previously unknown radiation beyond the violet end of the spectrum, which the human eye cannot detect.

Materials Needed

- several sheets of blueprint paper
- 1 qt (about 1 ℓ) of household ammonia
- flat pan
- prism or mirror in pan of water
- light source



Step 1: Using a prism or a pan of water, create a spectrum on a horizontal surface, such as a table. Use sunlight from an open window, as glass blocks most ultraviolet radiation. The prism should be resting on a stable object so that the spectrum does not move.

Step 2: Working quickly to prevent exposure of the paper to too much light, cut a piece of blueprint paper about four times larger than the spectrum. Place blueprint paper, which behaves the same way that Ritter's silver chloride paper did, underneath the spectrum. Quickly outline the area covered by the spectrum with a felt-tip pen. Label the violet end.

NOTE: Depending on the sensitivity of the paper, different exposure times will be needed. Most exposure times will be fairly brief, however: about 15 to 20 seconds.

Step 3: Put just enough ammonia in the pan to cover the bottom to a depth of about 0.5 in. (1 cm). In front of an open window or beneath a vent fan, hold the paper over the pan of ammonia so that the fumes will process the paper. Notice the changes in the area outlined and the area just beyond the violet end. You may have noticed that this area began to change even before processing with the ammonia.

Questions

1. What happened to the part of the paper lying where you can see violet?
2. What happened to the part of the paper lying just beyond that violet section?
3. What does this demonstrate about the area beyond the violet end of the spectrum?

INFRARED LIGHT

ACTIVITY J-6

GRADE LEVEL: 7-10

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What's This Activity About?

Students can readily appreciate optical astronomy, but exploration using other wavelength regions is often not as familiar. This activity is a wonderfully simple exploration of infrared light, which will help students understand how these longer wavelengths are detected and influenced by material in space. We use infrared radiation constantly with our television and VCR remote controls, and the use of these familiar devices is one great strength of this activity.

IR astronomy has made many important contributions to our understanding of the universe. Infrared astronomy has grown tremendously in the last two decades, helping scientists to peer behind the shrouds of gas and dust in our galaxy. With IR light, astronomers have glimpsed the process of star formation, discovered the composition of gas and dust in our galaxy, examined planetary atmospheres, and even looked at newborn galaxies. Infrared telescopes exist at many key astronomical observatories and usually at very high altitudes because water vapor in the Earth's atmosphere will otherwise absorb IR signals from space. IR satellites like IRAS have been launched into orbit, and an IR telescope even flies aboard the Kuiper Airborne Observatory aircraft, a special jet aircraft operated by NASA above most of the water vapor in our atmosphere.

What Will Students Do?

Students use TV remote control units to investigate how IR radiation passes through dust, but is blocked by water, and they compare IR light to optical light.

Tips and Suggestions

- This is an excellent homework activity. Consider following it with a slide show using images from the Infrared Astronomical Satellite (IRAS) or one in which students can compare visible light and IR images side by side.

What Will Students Learn?

Concepts

Infrared (longer wavelength) radiation

Absorption, reflection, and transmission of light

Inquiry Skills

Experimenting

Inferring

Reasoning

Big Ideas

Energy

Interactions

J-6. Infrared Light

PUBLIC TELEVISION'S FAMILY SCIENCE SHOW
NEWTON'S APPLE®

INFRARED LIGHT

What is infrared light and how does it work?

How do we detect infrared light? How is it produced and how does it compare with visible light? What are some of the technologies that take advantage of infrared radiation?

SHOW NUMBER
1112

David uncovers exciting technological advances that use infrared light.

Segment Length – 6:35

RESOURCES

Hewitt, P. (1995) *Conceptual physics* (2d ed.). New York: Addison-Wesley.

Kohn, B. (1967) *Light you cannot see*. Englewood Cliffs, NJ: Prentice-Hall.

Newton's Apple Classic Video: Show #209—*Thermographs*. GPN: (800) 228-4630.

Silverman, J., Mooney, J., & Shepard, F. (1992, Mar.) Infrared video cameras. *Scientific American*, pp. 78-83.

3-2-1 Classroom Contact videotape: *Animal Vision*. GPN: (800) 228-4630.

Additional sources of information
NASA Education Division
Mail Code F
Washington, DC 20546
(LANDSAT and EROS photos)

Eastman Kodak
Consumer information hotline:
(800) 242-2424
(for sources that sell and develop infrared film)

Edmund Scientific Company
101 E. Gloucester Pike
Barrington, NJ 08007
(609) 573-6250
(radiometer and diffraction gratings)

Community resources
Contact your local utility about a thermographic home energy audit.

INSIGHTS

When we talk about *infrared radiation*, we're really talking about a particular kind of light. If you combine infrared radiation with radio waves, microwaves, *visible light*, ultraviolet radiation, X rays, and gamma rays, you'll end up with a broad band of radiation frequencies called the *electromagnetic spectrum*. All of these types of *electromagnetic radiation* transfer energy through space via waves of oscillating electromagnetic fields. What distinguishes them from each other are the frequency of the oscillation and, consequently, the *wavelength*.

An object's molecules and electrons are always in motion, vibrating and radiating electromagnetic waves. When the object heats up and its temperature increases, the motion will increase and so will the average *wave frequency* and the intensity of the radiation. You can see this at work in a toaster oven. When you turn the toaster on, you can feel some heat, but you see no light. As more electric energy is supplied and the wires get hotter, they begin to glow red. If you could really turn up the power so that the temperature reached about 3,000°C, the wires, like the filament in a light bulb, would glow white. The only problem is that they would probably burn up before they reached that temperature.

British astronomer Sir William Herschel discovered infrared radiation around 1800. He used a prism and a sensitive thermometer to detect "invisible" light found just below the red portion of the spectrum. The term infrared (meaning "below red") came into use because it describes where you find it on the electromagnetic frequency spectrum.

Any warm object gives off infrared radiation. But remember, warm is a relative term. An ice cube in a cooler is warmer than a flask of liquid nitrogen, so it gives off more infrared radiation. Using special infrared scanners, a *thermographic* scanner takes these differences in radiation intensity, codes them by color, and maps them out so that "hot spots" can be detected. With this technology, engineers can find heat leaks in buildings, doctors can find hidden tumors in the body, and biologists can even find diseased vegetation in a forest.

Infrared imaging can even have applications in space. Astronomers use infrared imaging to detect warm dust around new stars not "hot" enough to give off visible light. This gives them a more complete picture of the whole universe, seeing where no one has seen before!

CONNECTIONS

1. Rattlesnakes and other reptiles can perceive infrared radiation. Does that mean they can see in the dark?
2. If you could only see in the infrared range, which would "light up" your life more—an electric iron or a fluorescent light?

VOCABULARY

electromagnetic radiation the transfer of energy by means of oscillating electromagnetic fields
electromagnetic spectrum the wide band of different types of electromagnetic radiation ranging from radio waves to gamma rays
infrared radiation or "light" invisible electromagnetic radiation that has a longer wavelength than visible light and is detected most often by its heating effect
thermograph a picture showing the differences in surface temperatures of an object
visible light the part of the electromagnetic spectrum that can be seen by humans
wave frequency the number of times a wave crest passes a point in a second
wavelength the distance between two successive wave crests

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SHOW NUMBER
1112

NEWTON'S APPLE®
PUBLIC TELEVISION'S FAMILY SCIENCE SHOW

REMOTE CONTROLLING

You will discover how infrared radiation behaves compared to visible light.

TRY THIS...

Kodak has developed infrared film that works in a standard 35-mm camera. This type of film can often be purchased at a well-stocked photography supply store. You can set up a test experiment by selecting several different targets and photographing them in both infrared and visible light. You'll be amazed at what develops!

TRY THIS...

Go into a dark room that has an incandescent light bulb controlled by a dimmer switch. Observe the spectrum it produces through a diffraction grating when the light is fully turned on. (See resources for diffraction gratings.) Slowly turn the dimmer switch down while observing through the grating. What happens to the spectrum? What connection does this have to infrared radiation?

MAIN ACTIVITY

Most television remote control units work by means of infrared radiation rather than visible light. That's why you can't see the beam go on when you change channels. Because infrared radiation has a longer wavelength than visible light, it behaves differently when it encounters objects that get in its way.

Using your television's remote control as a source of infrared radiation, you will compare the behavior of a beam of infrared radiation to that of a beam of visible light. You will see how each reacts when different materials are placed in its path.

Materials

- television set and remote control unit
- flashlight
- cornstarch baby powder
- clear glass of water

1. Clear all obstructions between you and the television set. Darken the room as much as possible. Stand about 3 meters (10') away from the set and test your remote control unit to make sure it is functioning properly. Test your flashlight by shining it against the dark television screen.

2. Have a friend stand about halfway between you and the television, directly in front of the screen. Try turning on the television using the remote control. Then try shining the flashlight onto the television screen. Observe what happens in each trial. Have your friend move around and notice how both "light" beams behave.

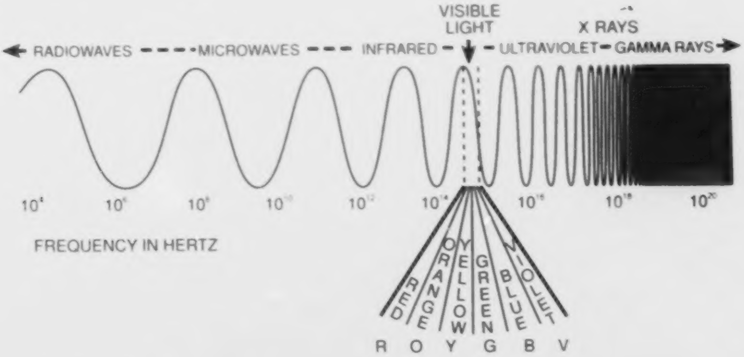
3. Have your friend blow some cornstarch baby powder in the air between you and the television and attempt to turn on the television through the dust. Repeat, using the flashlight, and observe what happens when you aim it at the screen.

4. Place the glass of water directly in front of the remote control unit and try to turn on the television. Now shine the flashlight through it. Note what happens in each case.

5. Hold the remote control in your right hand and place your left hand at several distances and angles relative to the remote control. Determine the conditions under which your hand motion prevents the signal from reaching the television.

Questions

1. Which of the objects interfered with the flashlight beam? Which stopped the infrared beam?
2. Why do you think infrared sensors are good at detecting hot spots in forest fires, yet have problems detecting warm bodies in the fog?
3. How does the longer wavelength of infrared radiation help to explain your observations?



TRY THIS...

For over 10 years, NASA has photographed Earth in the infrared range from satellites to measure long-term environmental changes. Contact NASA (see resources) to obtain LANDSAT infrared images of your community and see how the different "heat" colors show the commercial and residential developmental pattern.

TRY THIS...

Radiometers—those things that look like light bulbs with a weather vane inside—not only measure the intensity of visible light but react to infrared as well. Conduct an infrared survey by placing the radiometer near a variety of warm objects to see which has the most effect. The faster the "weather vane" spins, the more intense the radiation. (See resources for radiometers.)

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SPECTROSCOPES AND SPECTROMETERS

ACTIVITY J-7

GRADE LEVEL: 4-10

Source: Reprinted by permission from PASS (Planetarium Activities for Student Success), Vol. 8 *Colors and Space*. Produced by the Astronomy Education Program of the Lawrence Hall of Science, University of California, Berkeley. ©1993 by The Regents of the University of California. Available through the *Eureka!* catalog, Lawrence Hall of Science, University of California, Berkeley, CA 94720-5200; (510) 642-1016.

What's This Activity About?

How do we really know what space is made of? Or that stars contain hydrogen? How can we tell the masses of stars? Or that the universe is expanding? A vital part of the answer to all of these questions is spectra. Spectroscopy is such a key element of modern astronomy that understanding how it is applied is a critical part of our students' learning.

Two sets of activities are included—one for elementary grades, and an advanced experiment for middle or high school students. These activities are similar in that students investigate the spectra produced by gas discharge (emission) tubes.

What Will Students Do?

In the elementary version, students observe the patterns, colors, and differences of the spectra from five common gases. If gas discharge tubes are not available, students can examine common light sources using diffraction gratings. Even a fluorescent light can be used to detect an emission spectrum superimposed on a continuous background.

In the advanced version, students make a working spectrometer that can also measure the wavelengths of spectral lines. Students record the colors, pattern, and wavelengths of the lines from gas discharge tubes and common light sources.

Tips and Suggestions

- The plastic Project STAR spectrometer (available from the Astromical Society of the Pacific through its educational catalog or Learning Technologies) is an excellent and inexpensive resource for the advanced version of this experiment. The instrument includes calibrated energy and wavelength scales with a holographic diffraction grating in a sealed plastic body.
- For advanced students, tie spectral line positions to the Doppler shift principle, and then relate spectra to activities on binary stars, Hubble's law, quasars, and the expansion of the universe.

What Will Students Learn?

Concepts
- Gases
- Atoms
- Electrons
- Electromagnetic energy

Inquiry Skills
- Observing Systematically
- Comparing
- Ordering
- Communicating

Big Ideas
- Energy
- Structure
- Matter
- Patterns of Change

Spectroscopes

In this activity, students build simple spectroscopes with which they can quantitatively analyze emission spectra of elements and compounds.

Objectives

The elementary version is best used with younger classes (grades 2-6), while the advanced version is most appropriate for older classes (grades 6-9). In this activity, students will be able to:

1. Build a spectroscope.
2. Record the spectrum lines in emission spectra of elements.
3. Distinguish elements and compounds by examining their emission spectra.

Elementary Version

Materials

For each student:

- ☐ 1 square of diffraction grating (1")
- ☐ 1 cardboard tube, about 2" dia. x 4" long
- ☐ 2 railroad board squares, about 2-1/2" on a side
- ☐ 1 roll of clear tape
- ☐ 1 box of crayons containing red, orange, yellow, green, blue, violet
- ☐ 1 spectra worksheet (master on page 35)
- ☐ 1 scissors
- ☐ 1 pencil

For the class:

- ☐ 1 Light bulb (ideally, tubular, unfrosted) & socket

Optional:

- ☐ 1 Spectrum tube power supply*
- ☐ 1 Spectrum tube of each of the following gases:*

Hydrogen, Mercury, Helium, Water, Neon.

Even if you don't have access to spectrum tubes and power supply, this activity can be done by having your students construct their spectroscopes, observing various light sources, and comparing them with prepared posters of spectra of these elements as shown at the top of page 32.

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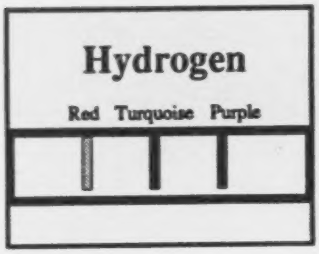
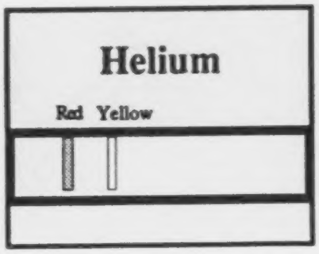
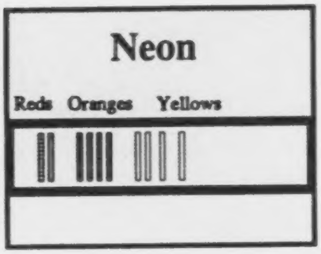
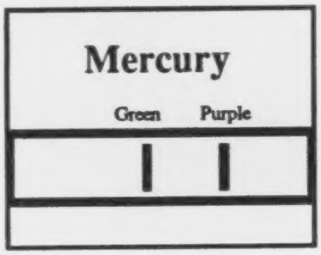








Before Class

1. Drill or punch a 3/4" hole in the center of half the railroad board squares. Drilling is most neatly accomplished with a drilling jig or by stacking the squares all together and sandwiching them between two pieces of scrap wood.

2. Gather all other supplies. For each student, make a copy of the worksheet.

In Class

1. One of the most important tools of the astronomer is a spectroscope which breaks light up into various colors. With spectroscopes, astronomers can tell what stars and comets are made of, and what's in a planet's atmosphere without having to go get samples. Getting samples, especially from stars, is impossible anyway. To see how a spectroscope works, each student will make his or her own simple spectroscope.

2. Making a spectroscope (For each step, demonstrate before handing out materials for doing the step.)

(i) Using the cardboard tube as a guide, draw circle outline on the railroad board square with the 3/4" hole in the center.

(ii) With scissors, cut out the circle.

(iii) Tape the diffraction grating square over the 3/4" hole, without covering the hole with tape. Caution your students to handle the diffraction grating square by the edges and not to get fingerprints on it.

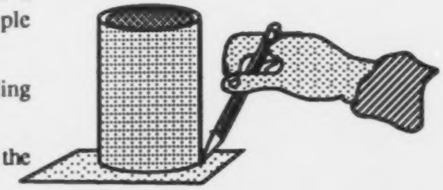
(iv) Tape the result of step 3 onto one end of the cardboard tube.

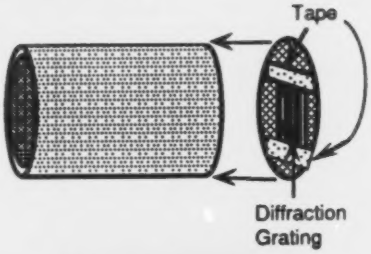
Optional:

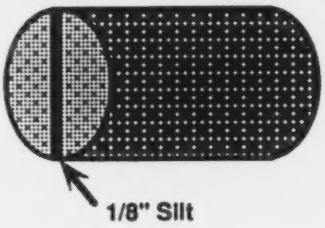
(v) Draw a circular outline of the tube on the second railroad board square, as in step (i), but without a hole in the center.

(vi) Cut out the disc, and cut the disc in half.

(vii) Tape the halves of the disc onto the end of the tube opposite the diffraction grating so that there is an approximate 1/8" slit between the halves. **Tape the half-discs so that they form a slit *perpendicular* to the direction of the color bands.**







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Turn on the bright white tubular unfrosted light bulb in the center of the room.

What do you see when you look through your spectroscope? (Rainbow colors)

Make sure the students hold the diffraction grating ends close to their eyes. Check with each student to see that they do in fact see a rainbow of colors. Tell the students that the best way to see the colors is to turn the spectroscope until a big wide band of colors is seen spreading out to the sides.

What color is closest to the light? (Purple.) **What color is next to that?** (Blue.) **Next?** (Green.) **Next?** (Yellow.) **Next?** (Orange.) **And finally?** (Red.)

Tell your class that the colors of a rainbow are always in the order they see here. Suggest that they notice that next time they see a rainbow in the sky. Have the whole class repeat together the colors of the rainbow as they see them in order from purple to red. Just for variety, have the whole class say the colors in order backwards (from red to purple).

A metal filament (usually tungsten) is giving off light inside the bulb. Since stars are made of gases, we are interested in seeing gases glow.

Optional: Show the spectrum tube (hydrogen)

In that tube is a gas called hydrogen, commonly found in stars. The tube can be made to glow by using the 10,000 volt light bulb socket (power supply). Hold your spectroscopes so that the colors spread sideways.

Turn the bright white light back on for them to readjust how they are holding their spectroscopes. Then turn the white light off and turn the hydrogen tube on.

How is this light different from the white light? (There are only certain thin lines of color.) **What is the brightest color line?** (Red.) **What are the two next brightest color lines?** (Turquoise and purple.)

Now hand out crayons and worksheets and have your students color what they see as the spectrum of hydrogen. Tell them how to spell hydrogen in the line next to "ELEMENT 1." Show the helium, neon, and mercury spectrum tubes and in each case, ask what the most prominent lines are and have your students color them on their worksheets.

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Every gas has a different "signature" of colors. This is how astronomers can tell what gases are in a star, comet, or planet atmosphere just by looking at the light through a spectroscope. You can see interesting spectra with your spectroscopes if you try looking at street lamps, neon store signs, and other bright light sources. Never look directly at the sun. [The sun displays a brilliant rainbow through the spectroscope but one must be careful to tilt the tube to one side and look only at the side of the tube farthest from the sun so that one is not looking directly at the sun through the end of the tube.] A safe way to observe the spectrum from the sun is to allow the sunlight to shine through the spectroscope and onto a piece of white paper or cardboard. You can observe an excellent spectrum right on the paper without having to look directly toward the sun.

Homework assignment: use your spectroscope, crayons and paper to record the spectra of (1) a streetlight, (2) a restaurant sign, (3) a fluorescent light. ***Can you identify the elements in the spectra you have drawn?***

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Drawing Spectra

Red	Orange	Yellow	Green	Blue	Violet

Element 1: ______________________

Red	Orange	Yellow	Green	Blue	Violet

Element 2: ______________________

Red	Orange	Yellow	Green	Blue	Violet

Element 3: ______________________

Red	Orange	Yellow	Green	Blue	Violet

Element 4: ______________________

Red	Orange	Yellow	Green	Blue	Violet

Element 5: ______________________

Red	Orange	Yellow	Green	Blue	Violet

Element 6: ______________________

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Spectroscopes—Advanced Version

How to build and use a

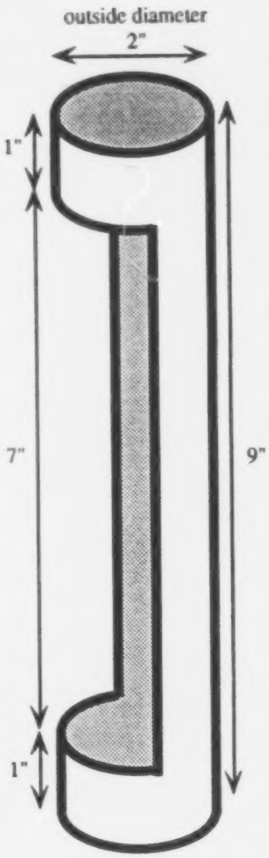
Spectrometer

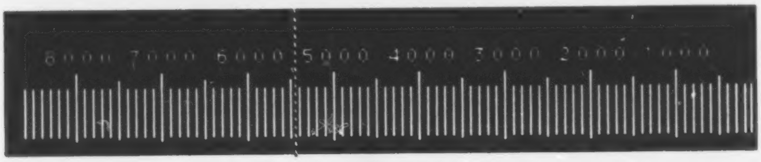
Materials

For each student:

- ☐ 12" x 16" darkly colored railroad board
- ☐ 9" cardboard tube 2" wide on the outside
- ☐ 1-3/4" cardboard tube 2" wide on the inside
- ☐ 2-1/4" cardboard disk with 1/4" hole in the center
- ☐ 1" square diffraction grating* (13,400 grooves/inch; not holographic)
- ☐ masking tape
- ☐ opaque tape (no light comes through)
- ☐ scissors and/or a sharp blade (be careful)
- ☐ wavelength scale (photocopy scales on page 41)
- ☐ pair of marking template sheets (masters on pages 42-43)

* Available from science supply companies such as Edmund Scientific Co., 101 E. Gloucester Pike, Barrington, NJ; Frey Scientific, 905 Hickory Lane, Mansfield, OH 44905, (800) 225-3739; Science Kit & Boreal Laboratories, 777 E. Park Dr., Tonawanda, NY 14150-6784, (800) 828-7777. Optionally, you can use holographic diffraction grating, but the spread of colors will be narrower, so you would have to reduce photocopy the wavelength scale to calibrate for accurate readings.





Preparation

Photocopy the scale pieces. Make a marking template for the body of the spectrometer by photocopying the two parts on pages 42-43, cutting them out, and taping them together, making the arrow heads overlap exactly. Cut the cardboard tubes to proper lengths. Half of the 9" tube must be cut away, but only the central 7". An inch of tube at each end must remain intact. Cut out cardboard disks and, with a hole punch, punch holes in the centers.

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In Class

A Spectrometer - What Will It Do?

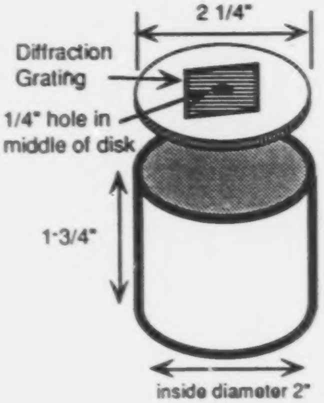
Our eyes perceive light in different colors. Some of the colors that we see are pure colors, but most of the colors we see are mixtures of different colors. A **spectrometer** can separate light that is a mixture of colors into a collection of pure colors. A collection of pure colors is called a **spectrum** (for more than one spectrum say spectra).

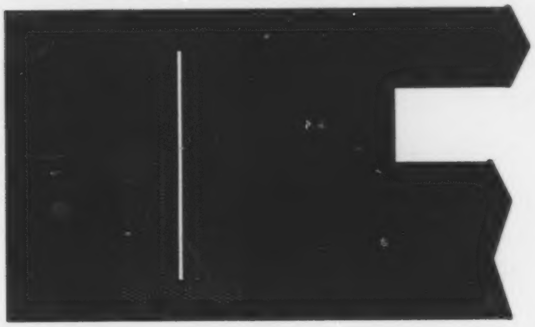
A spectrum that many people are familiar with is the one created when the pure colors that make up sunlight are separated as they shine on raindrops. It's a rainbow! The colors in a rainbow include every pure color that human eyes can see. Many of the spectra that the spectrometer shows you may look like rainbows. Some lights, however, produce only a few pure colors of light. Knowing what these colors are can give you information about what substances are giving off the light.

The spectrometer can give a measurement to describe each pure color. The spectrometer measures the color's **wavelength**. Light travels as a wave. The length between two crests of a light wave, its **"wavelength,"** determines what color it is. Light that is a mixture of different wavelengths is not a pure color and will be separated by the spectrometer. Wavelengths are very small so inches or centimeters are impractical for describing wavelengths. The spectrometer measures wavelengths in Ångstroms. One Ångstrom (abbreviated, 1Å) is one ten-billionth of a meter. A typical visable lightwave is a few thousand Ångstroms. You can use the spectrometer to see how long the wavelength is for different colors of light. (Another common way to describe wavelengths is in nanometers, but most standard American reference books use Ångstroms. Conversion is very simple: 1 nm = 10 Å)

Putting it together:

To assemble the eyepiece of the spectrometer tape the cardboard disk to one end of the 1-3/4" cardboard tube. Use plenty of tape to make it strong and to keep light from leaking in through any cracks, but make sure that the tape is on the **outside**. The inside must slide freely over the end of the 9" tube. Next tape the 1" square of diffraction grating material over the hole in the disc. Be careful not to let tape cover the hole itself. Look through the hole at any bright light. (Not the sun!) Already it is possible to observe specra. Bright lights in dark places work best. To observe spectra more clearly and to measure wavelengths you will have to build the body of the spectrometer.





The body of the spectrometer should be cut out of dark railroad board. Its outline can be traced onto the railroad board from the body template (master on pp. 42-43). The slot that is 1/4 inch wide is where the light shines into the spectrometer. Use the opaque tape to make this slot into a narrow slit. The narrower the slit, the more accurate the measurements can be. The wider the slit, the brighter the spectrum will appear. A slit 1mm wide is good. Use tape on both sides for extra strength.

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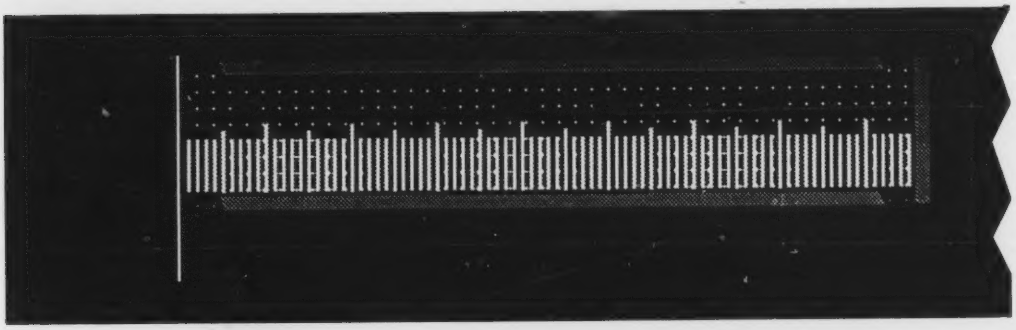
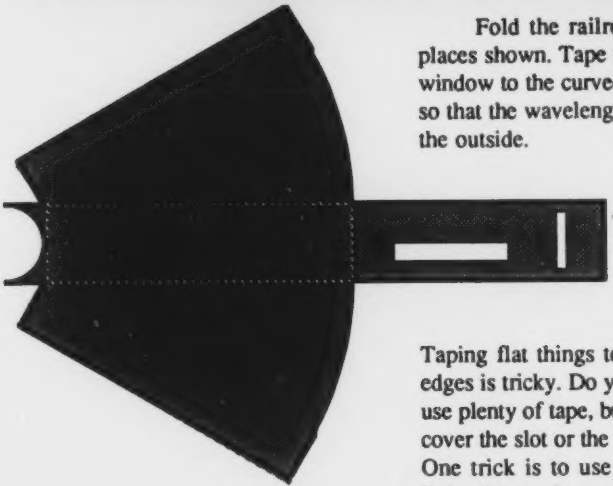
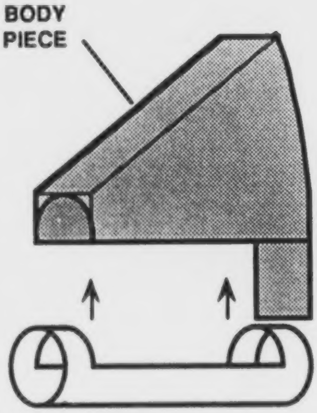
The other slot is the window for the wavelength scale. The wavelength scale must be cut out exactly along its edges. Tape it face down over the window so that its edge is exactly along the narrow slit but not covering it. Make sure that no tape covers either the slit or the window. It will appear as pictured below.



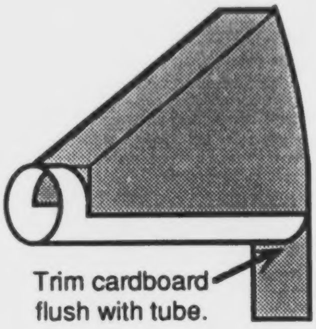


Fold the railroad board body in the four places shown. Tape the flap with the slit and the window to the curved edges of the railroad board so that the wavelength scale is still face down on the outside.



Taping flat things to curved edges is tricky. Do your best, use plenty of tape, but do not cover the slot or the window. One trick is to use a lot of little pieces of tape.

The 9" tube is the backbone of the spectrometer. Attach the railroad board to the 9" tube, as shown, making sure that the section of the tube that is cut out is inside the spectrometer. Trim away the overhanging part of the flap that has the slit and the window. Use enough tape to hold it all together and to seal up all the cracks, but never cover the slit or the window. Slide the eyepiece over the piece of tube that sticks out of the body and your spectrometer is complete.



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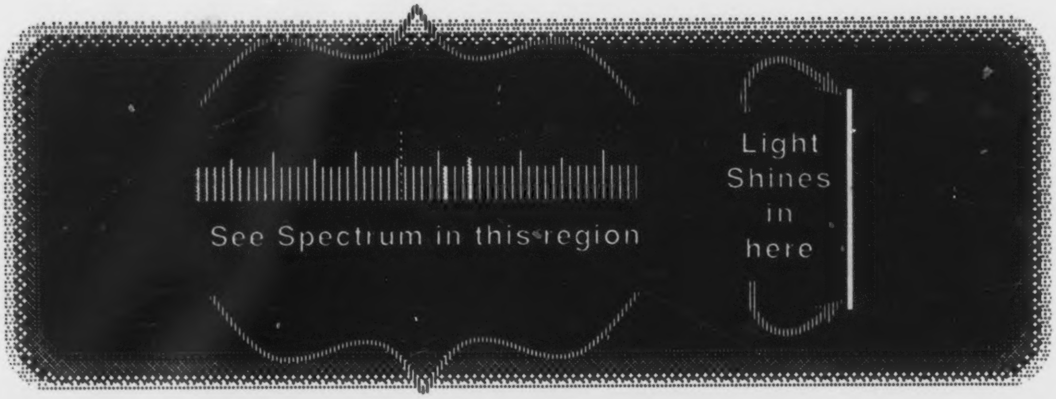

Using your spectrometer

Look through the spectrometer toward a fluorescent light. You should see the light through the slit and somewhere around it a spectum. At first it may be difficult to see a spectrum. Sometimes the spectrum shows up clearly only when the spectrometer is pointed slightly to one side of the light source. (Actually there are two spectra, one on either side of the light source.) Twist the eyepiece and the spectra will revolve around the slit. Position the eyepiece so that the spectra are on either side of the slit. One of them should lie on top of the wavelength scale.

The spectrum of a fluorescent light looks like a rainbow with a few brightly colored lines. The wavelength of the bright green line is about 5460Å. The final adjustment before taking any measurements is to pull the eyepiece in or out so that the bright green line appears on the dotted line on the wavelength scale. Tape the eyepiece into place. Now every color will appear on the scale in a position corresponding to its wavelength. If the eyepiece is moved for some reason, find a fluorescent light to readjust it correctly.

There are a few experiments that you can try right away. Look at any bright white light (but never the sun!). Most white light contains every wavelength that the human eye can see. ***What is the shortest wavelength that you can see? What is the longest wavelength that you can see?*** Different people may be sensitive to slightly different ranges of wavelengths, so answers to these questions may vary from person to person.

Using crayons or colored pencils or markers, do your best to draw the spectrum of white light as you see it through your spectrometer. Label some of the colors with their wavelengths. ***How many colors can you see in the spectrum of white light?*** Isaac Newton divided the spectrum into seven colors; red, orange, yellow, green, blue, indigo, and violet. Actually there are an infinite number of different colors. For instance the part of the spectrum that looks red has many different kinds of red, but we have only the word "red" to describe them all. That is one reason why it is handy to be able to measure a color's wavelength. The wavelength describes the color exactly.

Use your spectrometer to look at colored lights. Some colored lights are simply white lights that shine through colored substances such as paint or colored glass or plastic. These substances filter out some wavelengths of light. Your spectrometer will tell you which wavelengths get through.

Some colored lights are made with substances that give off light with only a few wavelengths. Neon signs give off light only with certain wavelengths in the red, orange and yellow parts of the spectrum. Neon also gives off a wavelength in the green part of the spectrum, but the combined light always appears orange. Find a neon light and draw its spectrum,

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labeling the colors with the wavelengths that you measure. Some lights that people call 'neon lights' contain no neon at all. If you can find some of these lights to observe with your spectrometer, note the wavelengths of the colors that are given off. The wavelengths are unique to each element. This means that the wavelengths that you observe can be used to identify what substances are giving off the light.

Even some lights that look white have certain wavelengths that are particularly bright. Many street lights are good examples of this. So are fluorescent lights. The bright green wavelength that you observe when looking at a fluorescent light is given off by mercury. Look in a physics reference book such as ***The Handbook of Chemistry and Physics*** for a table that shows the wavelengths for the emission spectra of the elements to find out what elements are giving off the other colors that you see in your spectrometer.

Happy spectrum watching!

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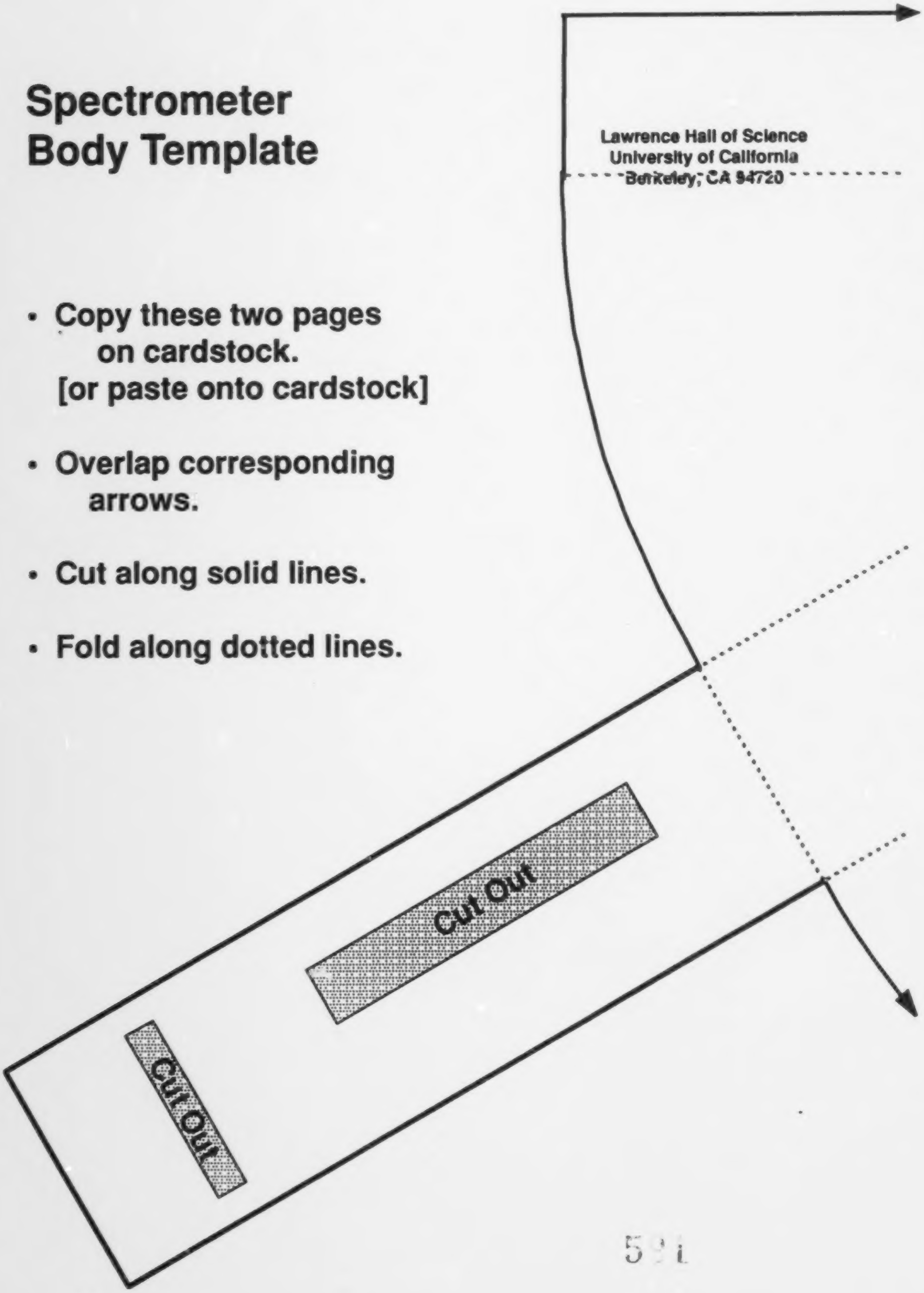
Spectrometer Body Template

- Copy these two pages on cardstock. [or paste onto cardstock]
- Overlap corresponding arrows.
- Cut along solid lines.
- Fold along dotted lines.


Lawrence Hall of Science
University of California
Berkeley, CA 94720
Cut Out
Cut Out

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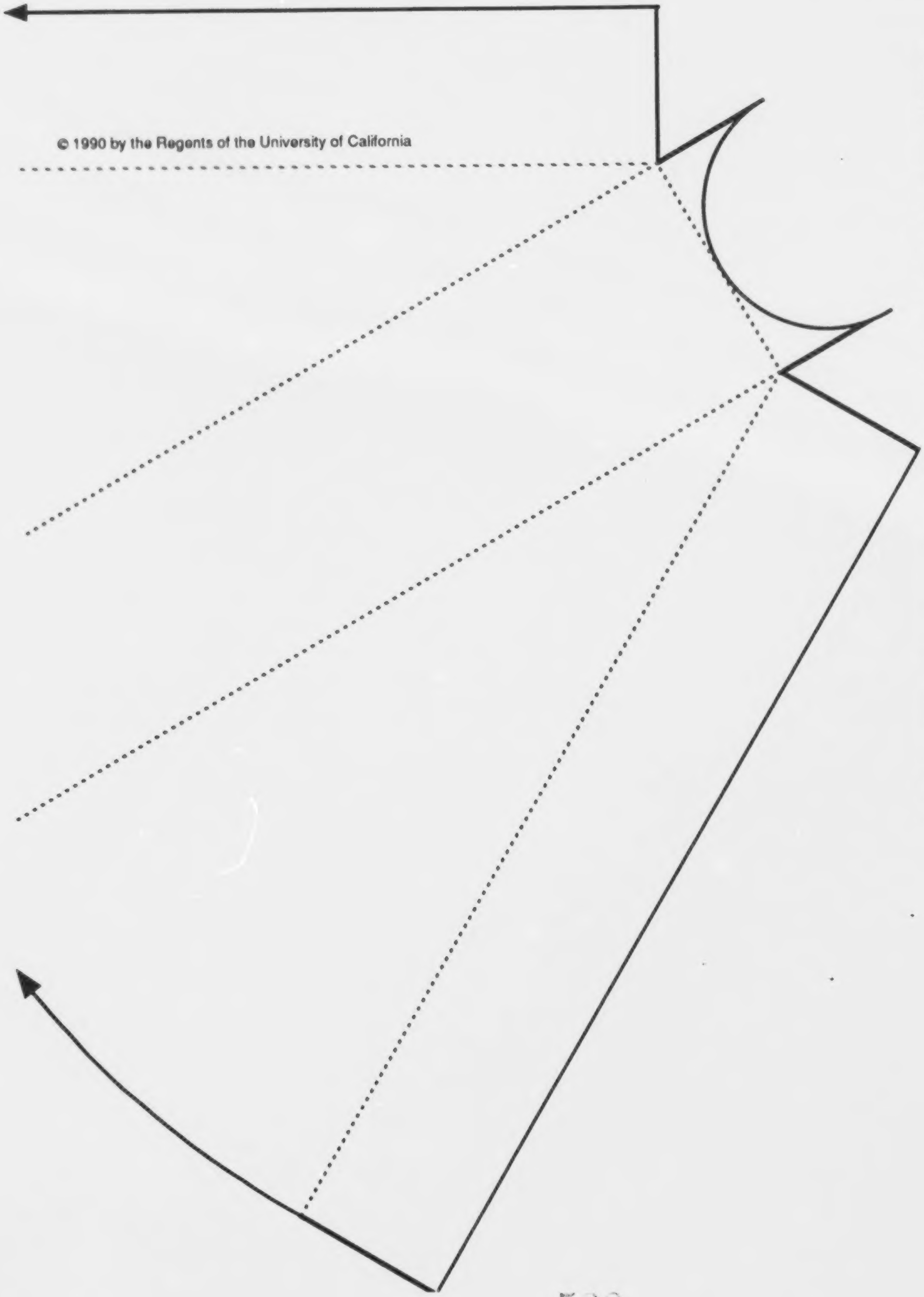
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Planetarium Activities for Student Success—Lawrence Hall of Science © 1993 by the Regents of the University of California

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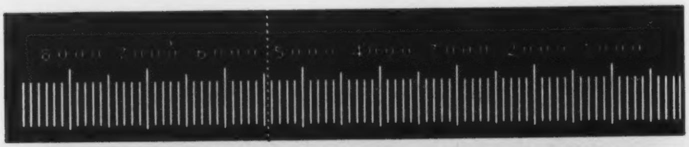
[Scales below for photocopying]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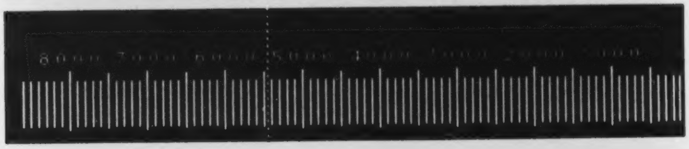
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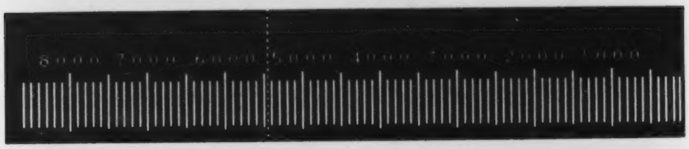
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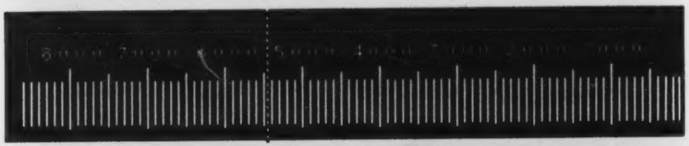
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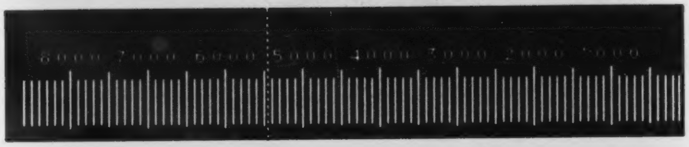
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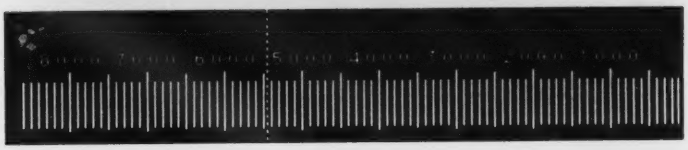
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LIGHT COLLECTING MODEL

ACTIVITY J-8

GRADE LEVEL: 4-7

Source: Public Domain

What's This Activity About?

This is a fast, simple activity to compare the amount of light collected by telescopes with different diameters. In astronomy, the size of a telescope is its most important asset. To collect the extremely faint light from distant stars and galaxies, astronomers need large collecting areas—the larger a telescopes mirror or lens is, the brighter and clearer the image it produces.

What Will Students Do?

Students count the number of pennies necessary to cover circles of different diameters. Student then graph their data and can see that the collecting area increases with the square of the diameter.

Tips and Suggestions

- Ask students to make an estimate of the number of pennies each circle will require before they do the experiment.
- One way to bring this concept directly into students' lives is to ask students to compare the size and cost of different sizes of one of their favorite foods—pizza! Compare the area of a large 16" pizza with that of a small 8" one, and assume that the thickness of the ingredients is the same in both cases. How many times the price of the smaller pizza should the price of the larger pizza be?
- For students familiar with the number "pi", you can compare actual areas (πr^2) with areas estimated using the number of pennies and the average area of a penny.

What Will Students Learn?

Concepts
Area
Diameter

Inquiry Skills
Measuring
Graphing
Predicting
Comparing

Big Ideas
Scale

LIGHT COLLECTING MODEL

PURPOSE

To compare the amount of light collected by telescopes of different apertures (sizes).

Circle (#)	**Diameter** (inches)	**Area** (# of pennies)
1		
2		
3		
4		
5		
6		

1. Measure each circle's diameter with a ruler and record the values in the data table.

2. Cover each circle entirely with pennies and record how many it takes in the data table.

3. Make a graph of your data using the supplied graph paper.

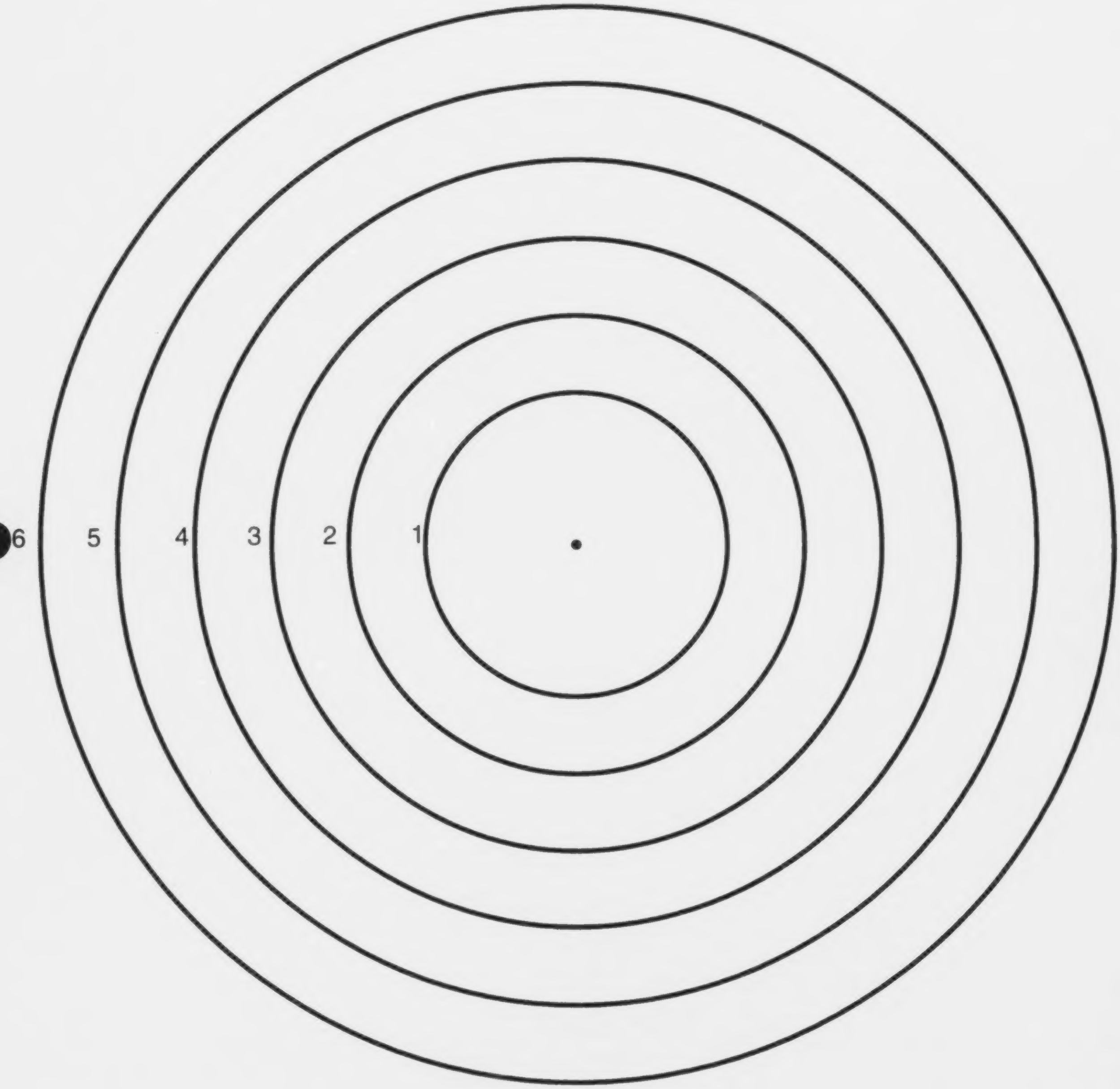
4. Answer the questions below after you have finished.

QUESTIONS

1. How does the amount of light (number of pennies) increase when you double the diameter of the circle?

2. Study your graph carefully. Predict the amount of light (number of pennies) that would enter through a telescope lens 8 inches in diameter.

3. What are some sources of error in this light collecting model?



WHAT MAKES GOOD VIEWING?

ACTIVITY J-9

GRADE LEVEL: 4-8

Source: Reprinted by permission from *Long Eyes on Space: Astronomy and You.* Copyright ©1991 The Vatican Observatory Foundation. Available from: Vatican Observatory Group, University of Arizona, Tucson, AZ 85721. $10 per single copy, or $8 each for 10 copies or more. (Pages may be copied for classroom use.)

What's This Activity About?

This activity will help students understand the factors that influence observing with telescopes, and why optical observatories are located far from people and as high as possible.

What Will Students Do?

Students start by brainstorming negative influences on the use of telescopes, like wind, heat, light, or fog, and then test their effects with experiments. Students investigate background light levels and how these affect our ability to see faint objects. Using hair dryers and dry ice, they investigate how air turbulence and clouds can interfere with observations.

Tips and Suggestions

This is a good activity to consider before a trip to an observatory. It can be used before discussing the role of telescopes like the Hubble Space Telescope and is also an excellent introduction to the issue of light pollution.

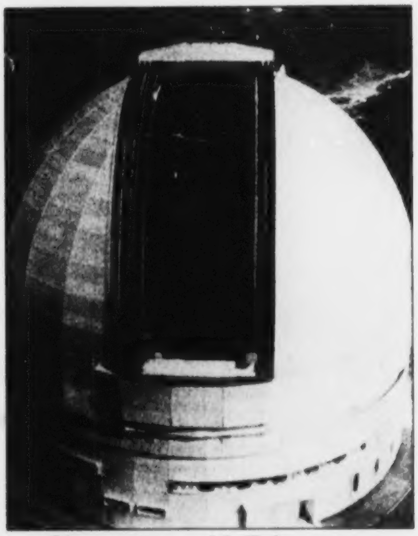
What Will Students Learn?

Concepts
- Optics
- Turbulence

Inquiry Skills
- Observing Systematically
- Experimenting
- Inferring
- Evaluating

Big Ideas
- Stability
- Interactions

WHAT MAKES GOOD VIEWING?



Observatory with Telescope

Many ***observatories***, places at which telescopes are located and astronomers work, are situated on high mountain peaks far away from city lights and other conditions which interfere with night viewing. One of the first Vatican telescopes was located on top of a church in Rome, Italy, and others began operation in the mid-1800s. Since then, the city lights of Rome have interfered with observations, so the Vatican Observatory has moved the location of some of its work to Arizona. Native American people in Arizona call astronomers "The People with Long Eyes" since they use telescopes to view distant objects in space.

The atmospheric conditions in Arizona make this location one of the finest in the world for viewing objects in space through telescopes. The University of Arizona's Steward Observatory, the Smithsonian Institution's Multi-Mirror Telescope on Mt. Hopkins, and the National Optical Astronomical Observatory on Kitt Peak are near Tucson. These locations allow astronomers to work on different projects, compare their findings and work together. This is why the Vatican Advanced Technology Telescope (VATT) is located in Southeastern Arizona.

Predictions: Based on your knowledge and understanding, what kinds of things could interfere with good "viewing", or being able to use telescopes effectively? Make your list here:

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________

Maybe some of the things you listed include lights from city, clouds, dust, fog, rain, snow, heat and wind. Let's test your guesses, or ***hypotheses***.

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Materials needed:

- hair dryer
- binoculars or cardboard tube
- matches
- small candle
- dark room
- dry ice
- tongs
- plastic container

Procedure for testing light interference:

1. Darken room as much as possible. (The room must be quite dark for good results.)
2. Light a small candle and place it on the far side of the room.
3. Note the brightness of the candle.
4. Allow some sunlight into the room.
5. Again note the brightness of the candle.
6. Fully light the room with natural and artificial light. Note the brightness of the candle.

Record your observations below by putting a check (✓) in the appropriate box.

	Degree of Candlelight		
Room Condition	*Bright*	*Moderate*	*Dim*
Fully darkened			
Partially darkened			
Brightly lit			

What can you infer about the effect the presence of light has on the ability to see the candle's flame clearly or view distant objects in space?

Procedure for testing wind and heat interference:

1. Focus binoculars at a distant object.
2. Turn on hair dryer and aim the hot air flow in front of the binoculars.
3. Remove the air flow while still focusing on the same object.

Record your observation here:

What can you infer about the effect of heat and wind on good viewing with telescopes?

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Procedure for testing cloud and fog interference:

1. Using tongs, place dry ice in plastic container.
2. Focus binoculars on a distant object.
3. Hold dry ice container just below the binoculars' line of sight, allowing the vapor to rise just in front of the binoculars.
4. Remove the dry ice container while still focusing on the same object.

Record your observations here:

What can you infer about the effect fog and clouds have on good viewing with telescopes?

Extended Challenge:

The ***atmosphere***, or air between us and space, needs to have several qualities in order for good viewing to be possible.

1. Based on your experiments, make a list of some of the atmospheric qualities needed for good viewing with telescopes.
2. What qualities does Arizona possess which make it a place for good viewing?
3. Where else in the world might ***astronomers***, scientists who study space, experience good viewing?
4. What are some of the advantages for putting telescopes on spacecraft or on the Moon?

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BUILDING AN OPTICAL TELESCOPE; MAKING A SIMPLE "PARABOLIC" REFLECTOR

ACTIVITY J-10

GRADE LEVEL: 6-9+

Source: Reprinted by permission from *Starfinder Activity Guide*. Copyright ©1990 Maryland INTEC, Maryland State Department of Education. To order, contact Maryland State Department of Education, 200 West Baltimore Street, Baltimore, MD 21201.

What's This Activity About?

The first activity leads students through the construction and use of a simple refracting telescope using plastic lenses. As students build the telescope, they can experiment with how the lenses magnify objects, and how images can be made clearer.

The second activity investigates improving radio reception using a foil-covered umbrella that acts like a parabolic reflector. After seeing pictures of a radio telescope, students might wonder why these instruments are shaped like great dishes. This demonstration will help students to see how radio waves can be focused.

What Will Students Do?

Using materials provided, students construct a simple telescope and investigate what the telescopes can resolve clearly. The second activity is a demonstration about focusing radio waves using an umbrella and aluminum foil.

Tips and Suggestions

- All of the materials to construct the simple telescope are available in kits from *Learning Technologies*, 59 Walden St., Cambridge MA 02140. The kits come with a more complete activity guide.
- The radio reception demonstration may be affected by your location and other interference from classroom walls. Try out the activity in the classroom first, and experiment at different locations in the room to find weak radio channels that are improved using the reflector.
- Try the experiment with an umbrella *not* covered with foil, and then covered with paper or chicken wire. Ask students to observe any differences. They should see that foil and chicken wire will focus radio waves fairly well, but non-metallic surfaces will not. You can use the chicken wire as a reflector because the wavelength of radio waves is greater than the size of the holes in the wire mesh. Slides of the giant reflecting dish at Arecibo, Puerto Rico, reinforce this concept, as gardens are seen growing underneath the wire mesh of the telescope.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Refraction	Experimenting	Energy
Reflection	Inferring	
	Observing	

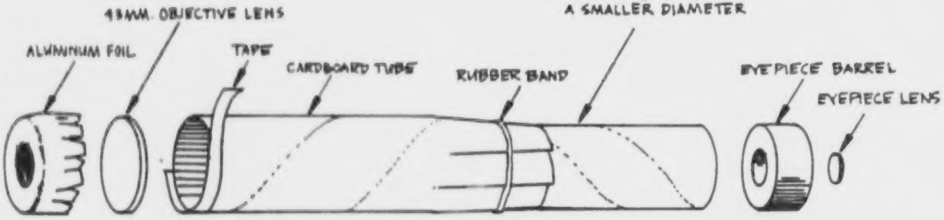
See for Yourself: Experiments/Projects

STARFINDER
PROGRAM 16

Building an Optical Telescope*

▶ **MATERIALS:**

- 43mm objective lens of 400 mm focal length**
- eyepiece lens of 25mm focal length**
- foam rubber ring eyepiece barrel**
- 2 cardboard tubes from paper towels or gift wrapping paper
  The tubes should have slightly different diameters.
- a rubber band
- masking tape
- aluminum foil
- paper and pencil
- compass
- scissors



▶ **DIRECTIONS:**

1. Center the eyepiece lens into the foam rubber ring. The convex side of the lens should face the ring's small hole.
2. Insert the foam ring into the smaller tube so that the edge of the ring is flush with the tube's end.
3. Insert and carefully tape the 43mm objective lens into the larger tube. The convex side of the lens should face out.
4. Cut a few slits into the top of the larger tube.
5. Fit the slitted end of the larger tube over the open end of the smaller tube and place a rubber band over the slitted area to hold the two tubes together. The smaller tube should be able to slide in and out to focus the telescope.
6. Use a compass to trace two circles, one 10mm and one 20mm in diameter onto a piece of paper. Cut out each circle with scissors. Place the circles in the center of two-four inch square pieces of aluminum foil. Carefully trace around each circle, poking out holes in the aluminum foil with a pencil point. The pieces of aluminum foil can now be molded over the front of the telescope whenever there is a need to cut down on the glare of bright objects, such as when viewing the moon or a planet. The foil is also useful in reducing chromatic aberration, a common problem among simple telescopes in which the lens acts like a prism to split light into a rainbow of colors. This gives objects that are observed a "false color."
7. This simple telescope is similar in many ways to one built and used by Galileo. Try taping it to a photo tripod to keep it steady for viewing. The images seen from the telescope are upside-down. Why?
8. Aim the telescope at various objects in the night sky. Record your observations in a logbook. Look for craters and mountain ranges on the moon.
9. Carefully observe stars and planets. They may look identical through this simple telescope, but there is a way to tell them apart. Make various sightings and record your observations. Next, place the aluminum foil over the front of the telescope to reduce glare and chromatic aberration. Look for and record any characteristics you notice about the objects sighted. If you discover that an object is very disc-like and does not twinkle with bright rays, you have probably discovered a planet. What characteristics can you record about the stars that you observe?

6 12

**Adapted with permission from Project STAR, Harvard-Smithsonian Center for Astrophysics.*

***Materials are available from Learning Technologies, Dept. T., 59 Walden St., Cambridge, Mass. 02140; 617/547-7724. Sets of plastic lenses and the eyepiece barrel cost $5 each or 10 for $20. Ten cardboard tube kits with lenses cost $30.*

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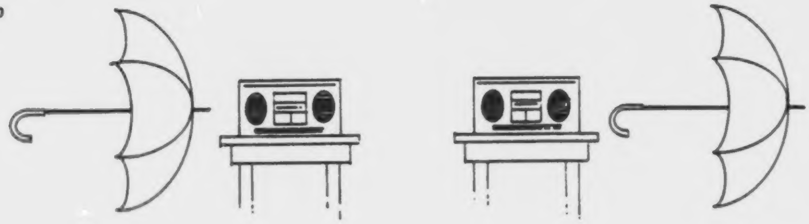
Making a Simple "Parabolic" Reflector

▶ **MATERIALS:**

- umbrella
- aluminum foil (heavy-duty is preferable)
- masking tape
- portable radio



▶ **DIRECTIONS**

Place the radio on a table. Open and line the inside of the umbrella with aluminum foil. Try to shape the foil so that it is as parabolic (bowl-shaped) as possible. Use masking tape to hold the foil in place. You will use this reflector to receive and to strengthen incoming radio signals.

1. **Turn the radio on and tune in to the lowest frequency. Survey and record all of the frequencies of the radio stations heard. Indicate which radio signals are particularly weak.**
2. **Hold the umbrella's parabolic reflector so that it faces the radio and can focus the incoming signal back to the radio's antenna. Tune in to the weakest stations received and note if there is any improvement to their signals.**
3. **Survey the stations again and record if any additional stations were picked up when using the parabolic reflector.**
4. **While receiving a radio signal, turn the umbrella around so that the parabolic reflector is no longer facing the radio. Record any changes in signal strength relative to the different placement of the umbrella.**
5. **Explain how this simple parabolic reflector is able to receive and strengthen radio signals.**

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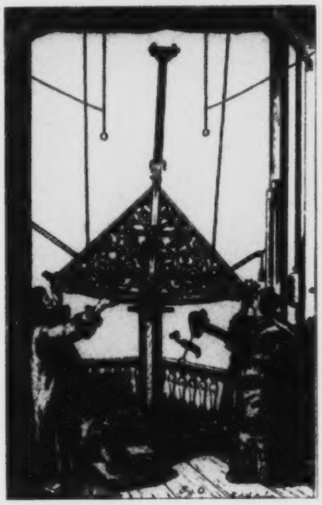


RESOURCES FOR EXPLORING TELESCOPES ASTRONOMERS USE

by *Andrew Fraknoi*
Astronomical Society of the Pacific
390 Ashton Ave.
San Francisco, CA 94112

NOTE: Readings marked with a • are especially useful for those just beginning their exploration of astronomy.

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

On Telescopes in General

• Cohen, M. *In Quest of Telescopes.* 1980, Sky Publ. & Cambridge U. Press. An astronomer shows what it's like to use the large modern observatories.

Krisciunas, K. *Astronomical Centers of the World.* 1988, Cambridge U. Press. Historical survey of the major observatories of each epoch, with a good emphasis on what is happening today.

Preston, R. *First Light.* 1987, Atlantic Monthly Press. A superbly written introduction to how astronomy is done today with the 200-inch telescope on Palomar Mountain.

• Tucker, W. & K. *Cosmic Inquirers.* 1986, Harvard U. Press. An introduction to the building and work of major telescopes on Earth and in space.

Learner, R. *Astronomy Through the Telescope.* 1981, Van Nostrand Reinhold. Good illustrated history of how telescopes helped advance astronomy.

Cornell, J. & Carr, J., eds. *Infinite Vistas: New Tools for Astronomy.* 1985, Scribners.

Ressmeyer, R. *Space Places.* 1990, Collins. A magnificent picture album of observatory and instrument photographs.

See any introductory textbook in astronomy for a concise guide to the basic principles of how telescopes work and how they are used in astronomy.

Teske, R. "Starry, Starry Night: Observing on Kitt Peak" in *Mercury*, Jul/Aug. 1991, p. 115. What it's like to use a telescope at the national observatory.

Wolff, S. "The Search for Aperture: A Selective History of Telescopes" in *Mercury*, Sep/Oct. 1985, p. 139.

Sinnott, R. & Nyren, K. "The World's Largest Telescopes" in *Sky & Telescope*, July 1993, p. 27.

• McPeak, W. "Building the Glass Giant of Palomar" in *Astronomy*, Dec. 1992, p. 30.

Keel, W. "Galaxies Through a Red Giant" in *Sky & Telescope*, June 1992, p. 626. On the 6-meter telescope in the former Soviet Union.

Bunge, R. "Dawn of a New Era: Big Scopes" in *Astronomy*, Aug. 1993, p. 49.

Janesick, J. & Blouke, M. "The Sky on a Chip: The Fabulous CCD" in *Sky & Telescope*, Sep. 1987, p. 238. On the electronic detectors that are revolutionizing modern astronomy.

The Hubble Space Telescope

• Field, G. & Goldsmith, D. *The Space Telescope.*

1990, Contemporary Books. Best layperson's introduction to the workings and projects of the Hubble Space Telescope, but it was written before the mirror flaw was discovered. (An excerpt appeared in *Mercury* magazine, Mar/Apr. 1990, p. 34.)

Chaisson, E. *Hubble Wars*. 1994, Harper Collins. Controversial inside story of the political and scientific considerations behind the Hubble, by a scientist who worked for the project.

Maran, S. "Hubble Illuminates the Universe" in *Sky & Telescope*, June 1992, p. 619. Excellent review of the science results before the mirror repair.

Chaisson, E. "Early Results from the Hubble Space Telescope" in *Scientific American*, June 1992, p. 44. Also summarizes the work done before the repair mission.

Gonzaga, S. "Anyone for a 94-inch Telescope: Amateurs Use the Hubble" in *Astronomy*, Dec. 1991, p. 43. Time was set aside for several projects conceived by amateurs.

- Maran, S. "The Promise of the Space Telescope" in *Astronomy*, Jan. 1990, p. 38. Written before the mirror problem was discovered, but a nice overview of the instrument.

Fienberg, R. "Hubble's Image Restored" in *Sky & Telescope*, Apr. 1994, p. 20ff. Good summary of the repair mission and the first images.

Bruning, D. "Hubble Better than New" in *Astronomy*, Apr. 1994, p. 44.

The Keck Telescope

Gustafson, J. & Sargent, W. "The Keck Observatory: 36 Eyes Are Better Than One" in *Mercury*, Mar/Apr. 1988, p. 43. On the plans for the world's largest visible-light telescope.

Harris, J. "Seeing a Brave New World: The Keck Telescope" in *Astronomy*, Aug. 1992, p. 22.

- Krisiciunas, K. "Science with the Keck Telescope" in *Sky & Telescope*, Sep. 1994, p. 20.

Ressmeyer, R. "Keck's Giant Eye" in *Sky & Telescope*, Dec. 1992, p. 623.

On Telescopes Used to Observe Invisible Radiation

- Field, G. & Chaisson, E. *The Invisible Universe*. 1985, Birkhauser Boston. An introduction to astronomy done by observing non-visible types of radiation.

- Friedman, H. "Discovering the Invisible Universe" in *Mercury*, Jan/Feb. 1991, p. 2. Good introduction to the instruments that reveal the radio, infrared, and x-ray universe.

Bunge, R. "Big Ears" in *Astronomy*, Aug. 1994, p. 34. On the inauguration of the network of connected radio telescopes spanning North America.

Hurley, K., et al. "Probing the Gamma-Ray Sky" in *Sky & Telescope*, Dec. 1992, p. 631. On the first year of the Compton Telescope, the "Hubble Telescope" for gamma-rays.

Kondo, Y, et al. "IUE: 15 Years and Counting" in *Sky & Telescope*, Sep. 1993, p. 20. On the work of the most important ultraviolet telescope.

Overbye, D. "The Secret Universe of IRAS" in *Discover*, Jan. 1984, p. 14. On the work of the Infra-Red Astronomical Satellite.

Shore, L. "VLA: The Telescope that Never Sleeps" in *Astronomy*, Aug. 1987, p. 15. On the large array of radio telescopes in New Mexico.

- Stephens, S. "Telescopes that Fly" in *Astronomy*, Nov. 1994, p. 46. On using the Kuiper Airborne Observatory for infrared astronomy.

Tucker, W. & Giacconi, R. *The X-Ray Universe*. 1985, Harvard U. Press. Introduction to the work of x-ray astronomers.

Verschuur, G. *The Invisible Universe Revealed: The Story of Radio Astronomy*. 1987, Springer Verlag.

SELECTED READINGS FOR STUDENTS

Grades 4-6

Ardley, N. *Exploring the Universe*. 1988, Schoolhouse Press. Introduction to visible-light and non-visible-light telescopes, with nice color illustrations.

Asimov, I. *Astronomy Today*. 1990, Gareth Stevens. Primer on telescopes, astronomers, and doing astronomy.

Couper, H. & Henbest, N. *Telescopes and Observatories*. 1987, Franklin Watts. A good selection of information.

Schultz, R. *Looking Inside Telescopes and the Night Sky*. 1993, John Muir Books.

Branley, F. *Space Telescope*. 1985, Crowell. Nice introduction, but written before launch.

Villard, R. "The Hubble Space Telescope: Expanding Our View of the Universe" in *Odyssey*, May 1993, p. 18.

Walz-Chojnacki, G. "Hubble Goes to Work" and "Fixing Hubble's Troubles" in *Odyssey*, Jan. 1991, p. 4 and 32.

Opalko, J. "Telescopes that Work While Astronomers Sleep" in *Odyssey*, June 1992, p. 16.

Vogt, G. "Build a Model of the Hubble Space Telescope" in *Odyssey*, 1990, issue 8, p. 28. Has a template for cutting out and assembling a model of the Hubble.

"Mirror, Mirror in the Sky" in *Odyssey*, Apr. 1992, p. 32. On the Keck Telescope.

Grades 7-9

Darling, D. *The New Astronomy: An Ever-Changing Universe*. A fact-filled introduction to telescopes, especially those observing invisible radiation.

SELECTED AUDIOVISUAL MATERIALS

Telescopes of the World (1982 slide set, Astronomical Society of the Pacific) 50 slides of the major instruments in and above the world, as of the early 1980's.

Keck Telescope: New Window on the Universe (1994, 13-min video from the Astronomical Society of the Pacific) A brief introduction to the largest visible-light-gathering telescope.

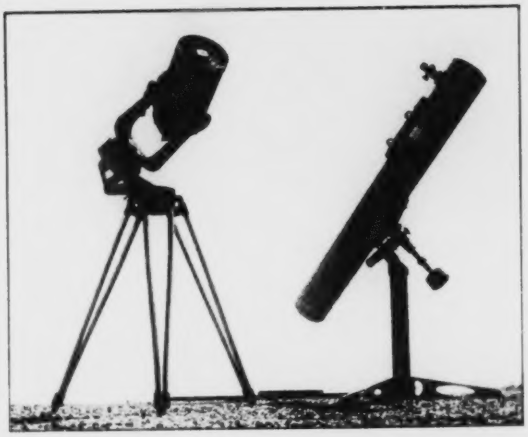
An Observing Run at Kitt Peak (slide set from JLM Visuals) Follows an astronomer as he observes at the country's national observatory.

Hubble Space Telescope: Rescue in Space (50-min video from Finley Holiday Films) On the telescope's repair, with commentary by the astronauts.

Hubble Space Telescope (3 slide sets from the Astronomical Society of the Pacific) Set 1 shows the telescope, its launch, and some early images; set 2 shows computer-processed images taken before the repair mission; set 3 shows the repair mission and later images. An even larger set is available from NASA CORE.

Countdown to the Invisible Universe (1984 video, WGBH or the Astronomical Society of the Pacific) On the Infra-Red Astronomical Satellite; an episode of the NOVA TV series.

Compton Gamma-Ray Observatory (slide set from the Astronomical Society of the Pacific) On the work of the major gamma-ray telescopes in space.



RESOURCES FOR EXPLORING TELESCOPES AND BINOCULARS FOR BEGINNERS

by Andrew Fraknoi

Astronomical Society of the Pacific
390 Ashton Ave.
San Francisco, CA 94112

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

Astronomy Magazine: Observer's Guide 1995. Kalmbach Publishing. This wonderful paperback guide to the sky also contains a good series of articles on buying telesopes, binoculars, eyepieces, and observing accessories.

Berry, R. *Build Your Own Telescope.* 1985, Scribner's. The definitive step-by-step guidebook for making a telescope.

Brown, S. *All About Telescopes.* 1975, Edmund Scientific. An old-fashioned guide book for first time telescope users, illustrated with many drawings. Available from Edmund, a mail order supply house (101 E. Gloucester Pike, Barrington, NJ 08007)

Gibson, B. *The Astronomer's Sourcebook.* 1992, Woodbine House, 5615 Fishers Lane, Rockville, MD 20852. A guide that includes addresses of manufacturers.

Harrington, P. *Star Ware.* 1994, John Wiley. Amateur astronomers' guide to buying and using your own telescope. Good for beginners or those upgrading their first telescope.

Berry, R. "A Beginner's Guide to Telescope Types" in *Astronomy*, Aug. 1981, p. 43.

Dickinson, T. "Choosing a Low-Cost Telescope" in *Sky & Telescope*, Dec. 1993, p. 59.

Editors of *Astronomy*: "The 1994 Telescope Buyer's Guide" in *Astronomy*, Nov. 1993, p. 58. A 16-page supplement with brand names.

Harrington, S. "Selecting Your First Telescope" in *Mercury*, Jul/Aug. 1982, p. 106.

MacRobert, A. "How To Choose a Telescope" in *Sky & Telescope*, Dec. 1983, p. 492.

Dyer, A. "Choosing Eyepieces: A Buyer's Guide" in *Astronomy*, June 1993, p. 56.

Maeda, K. "Build Your Own Radio Telescope" in *Sky & Telescope*, Aug. 1990, p. 200.

Shibley, J. "T is for Telescope: A Guide for First-time Buyers" in *Astronomy*, Nov. 1994, p. 70.

Both *Sky & Telescope* and *Astronomy* magazines have begun running excellent consumer reports on specific telescopes for hobbyists.

Binoculars

Editors of *Astronomy*: "Buying Binoculars for Astronomy" in *Astronomy*, Nov. 1992, p. 58. A special 16-page supplement.

Levy, D. "Discovering Binocular Astronomy" in *Astronomy*, Dec. 1985, p. 44.

Morris, K. "Binoculars for Astronomy" in *Astronomy*, Dec. 1986, p. 71.

Harrington, P. *Touring the Universe Through Binoculars.* 1990, John Wiley. Mainly an observing guide, but has good information on selecting binoculars.

Moore, P. *Exploring the Night Sky with Binoculars.* 1986, Cambridge U. Press.

SELECTED READINGS FOR STUDENTS

Matloff, G. *Telescope Power.* 1993, John Wiley. A guide to buying and using telescopes, with a number of useful activities.

Editors of *Odyssey*: "Your First Telescope" in *Odyssey*, 1990, issue 10, p. 4. A good guide for first-time buyers.

K

DEBUNKING PSEUDOSCIENCE

ACTIVITIES INCLUDED IN DEBUNKING PSEUDOSCIENCE

ACTIVITY	ESTIMATED GRADE LEVEL											
Grades	1	2	3	4	5	6	7	8	9	10	11	12
K-1. What's Your Sign? Students model the signs of the zodiac and demonstrate why certain constellations are aligned with the Sun but are not visible.				▨	▨	■	■	■	■	▨	▨	▨
K-2. Activities About Astrology Students evaluate Sun sign horoscopes for famous people and test newspaper predictions for validity, to show that astrology is a pseudoscience.							■	■	■	▨	▨	▨
K-3. UFO Detective Students discuss and investigate UFO reports.				■	■	■	■	■	■	▨	▨	▨

■ - Grade levels recommended by authors ▨ - Can be extended to these grade levels.

About the Activities: Debunking Pseudoscience

KEY IDEAS IN "DEBUNKING PSEUDOSCIENCE"

- An especially interesting context in which students can learn about the differences between science and pseudoscience is astrology.
- For many centuries astrology provided a reason for people to improve observations and predictions for locating the planets, thus spurring the development of the science of astronomy.
- When it became widely recognized that the Earth is one planet within the solar system, it was impossible for the geocentric discipline of astrology to adapt, and it gradually fell into disfavor.
- The *Benchmarks* cautions that students should not be allowed to conclude that the mutability of science permits any belief about the world to be considered as good as any other belief. Theories compete for acceptance, but the only serious competitors are those theories that are backed by valid evidence and logical arguments.

Our students may or may not grow up to be astronomers, but we would like them to at least understand what science is, and what scientists do. Doing science activities and meeting real scientists are some of the most important ways of accomplishing that. However, it is also valuable to teach our students what science is not; by providing examples of activities that may give the appearance of science, but which lack the objectivity or the experimental method that marks the boundary between science and pseudoscience.

An especially interesting context in which students can learn about the differences between science and pseudoscience is astrology. There are also good reasons to learn about astrology in its own right, as the historical antecedent of astronomy. Despite the widespread interest in reading the horoscope in the daily newspaper, few people know about the meaning of common astrological terms, or of the rich history of astrology as it has been practiced for more than two thousand years.

In ancient times astrologers did more than tell people if they'll have a good day, or advise a couple if they are likely to be compatible. Astrologers were asked to tell the fortune of an entire city or country, to say whether or not an army should go to war, or who should be thrown into jail or burned for a crime. Astrology was serious business and no competent astrologer would offer advice on the basis of a person's Sun sign alone. Astrologers had to determine the precise positions of all of the visible planets and interpret their significance. For many centuries astrology provided a reason for people to improve observations and predictions for locating the planets, thus spurring the develop-ment of the science of astronomy. Such famous scientists as Tycho Brahe and Galileo made money as astrologers.

From time to time, arguments among astrologers would erupt about how to apply the principles of their art as it was inherited from ancient Greek and Roman astrologers. For example, the slow wobble of the Earth's axis meant that by the 16th century the astrological sign no longer corresponded to the constellation of the same name. A planet in the sign of Taurus, for example, would be some distance away from the familiar constellation of Taurus the Bull. Some astrologers thought the signs should be changed to correspond to the constellations. Arguments such as these meant that different astrologers would make entirely different predictions based on the same data.

Eventually, most people lost confidence in astrologers, along with magicians, alchemists, and other practitioners of the occult arts. It is probably not a coincidence that this occurred during the late Renaissance, with the rise of the scientific worldview. Unlike scientific theories, which can change with new discoveries, the guiding principles of astrology are inherited from ancient authorities. When it became widely recognized that the Earth is one planet within the solar system, it was impossible for the geocentric discipline of astrology to adapt. If people are not, after all, at the center of the universe, with the Sun, Moon, and all the planets revolving around us, then perhaps the cosmos does not have a profound "influence" on us after all. With their confidence in astrology shaken, people were more critical of the failures of astrologers to predict future events.

The *Benchmarks for Science Literacy* recognizes that when students first understand that scientific theories are not absolute, there is a danger that they will react by thinking that all ideas are equally valid. "Students should not be allowed to conclude, however, that the mutability of science permits any belief about the world to be considered as good as any other belief. Theories compete for acceptance, but the only serious competitors are those theories that are backed by valid evidence and logical arguments." (*Benchmarks*, page 13.)

The activities in this section are designed to help your students recognize some of the differences between astronomy and astrology. They are based on the premise that the more students learn about science and pseudoscience, the better they will be able to distinguish the two.

Radar Image of Fotla Corona on Venus (Resembling "Miss Piggy")

BACKGROUND: ASTRONOMICAL PSEUDOSCIENCE

By Andrew Fraknoi

Few things excite the human imagination more than an unsolved mystery. In recent years, enormous public and media attention has focused on several topics that appear to be unsolved mysteries on the frontiers of science (although the evidence for them is often insubstantial and anecdotal). These topics include several that claim some connection with astronomy, such as astrology, faces on other planets, or contact with extraterrestrial visitors.

Many scientists and teachers dismiss the often far-fetched claims in these areas with a sarcastic comment. How likely is it, after all, that the alignment of the Sun, Moon, and planets at his birth would continue to influence Sylvester Stallone's love-life? Or that alien spacecraft would travel here across trillions of miles of space, pick up some Earthlings in the back woods, drop them off again, and go home — all without leaving a single piece of physical evidence behind?

But I would submit that we do our students a serious disservice when we dismiss these pseudoscience ideas without discussing them clearly and forthrightly. After all, quite independent of their work in school, students will come across such suggestions again and again, on television, in the newspapers, in the movies, and in discussions with their peers. Far better that those of us who work in the classroom try to help students think through how to evaluate such claims skeptically and how to decide which to explore further and which to dismiss. Such a discussion can be an ideal way of getting students to think about the scientific method and how scientists deal with controversial or surprising ideas.

The good news for those of us willing to help students in this way is that scientists, educators, and skeptical people from other fields have recently begun to investigate claims at the fringes of science and have even formed an organization to help disseminate the results of their research. The organization has an awkward name, The Committee for the Scientific Investigation of Claims of the Paranormal, but its heart is in the right place, and its magazine, *The Skeptical Inquirer*, is the single best source for teachers and astronomers who want objective information about astronomical pseudoscience (see the list of addresses in the Resources section of the notebook).

And what their investigations show is clear and unequivocal. When the "mysteries" at the fringes of science are examined more closely, most of them turn out to evaporate, leaving behind a cold trail of human gullibility, human frailty, and (perhaps most sadly) human greed. The face on Mars is a natural formation of sand with just the right combination of light and shadow, the predictions of astrology have failed test after scientific test, and as far as UFO's are concerned, there is a lot less to them than meets the eye.

All of which is not to say that it is impossible that an extraterrestrial spacecraft will land on Earth, or that we will discover remnants of an alien civilization somewhere. No scientist worth his or her salt will ever say that something is *a priori* impossible. But as Carl Sagan has pointed out, extraordinary claims in science require extraordinary proof. When the evidence is in, scientists will welcome and examine it. (When an alien spacecraft arrives on Earth, I suspect astronomers will be among the first to line up for some cosmic conversation.) But what we must teach our students is that in the absence of evidence, skepticism is the healthy attitude to take. I suspect students could profitably apply such skepticism to advertising or political claims as well.

The activities and resources in this section can help both adults and youngsters look more carefully at a few areas at the fringes of science and develop skeptical (detective) skills for sorting through the evidence and the claims.

Astrology

YOUR ASTROLOGY DEFENSE KIT

MAHARISHI
ABU BEN GEGENSCHEIN
Ph.D.
CUT-RATE
GRADUATE SWAMY
HOROSCOPES
CAST
WHILE U WAIT!
(CELESTIAL MECHANIC ON DUTY)
Fee Schedule
Regulation Horoscope
Bode's Law Special
Rigorous, Non-LTE Horoscope
(OUR SPECIALTY)
with Relativistic Correction
SPECIAL TODAY
Wish Upon a Star
PHRENOLOGICAL READINGS
(Plane Parallel Approx.)
CLOSE OUT
J.E.

Drawing by John Eddy

by Andrew Fraknoi
Astronomical Society of the Pacific
390 Ashton Avenue
San Francisco, CA 94112

It happens to all of us—astronomers, amateurs, and teachers. We tell someone about our interest in the heavens and quickly get drawn into a debate about astrology. For many of us it's hard to know how to respond politely to someone who takes this ancient superstition seriously.

The revelation that daily schedules in the Reagan White House were arranged and rearranged based on the predictions of a San Francisco astrologer focused new attention on astrology's widespread public acceptance. More than ever, we are likely to face questions about astrology, especially among young people. So here is a quick guide to some of the responses you can make to astrologers' claims.

The Tenets of Astrology

The basis of astrology is disarmingly simple: a person's character and destiny can be understood from the positions of the Sun, Moon, and planets at the moment of his or her birth. Interpreting the location of these bodies using a chart called the horoscope, astrologers claim to predict and explain the course of life and to help people, companies, and nations with decisions of great import.

Implausible as such claims may sound to anyone who knows what and how distant the Sun, Moon, and planets really are, a 1984 Gallup Poll revealed that 55 percent of American teenagers believe in astrology. And every day thousands of people around the world base crucial medical, professional, and personal decisions on advice received from astrologers and astrological publications.

The details of its precise origins are lost in antiquity, but astrology is at least thousands of years old and appears in different forms in many cultures. It arose at a time when humankind's view of the world was dominated by magic and superstition, when the need to grasp the patterns of nature was often of life-and-death importance.

Celestial objects seemed in those days to be either gods, important spirits, or, at the very least, symbols or representatives of divine personages who spent their time tinkering with humans' daily lives. People eagerly searched for heavenly signs of what the gods would do next.

Seen in this context, a system that connected the bright planets and "important" constellations with meaningful life questions was appealing and reassuring. (Astrologers believe that the important constellations are the ones the Sun passes through during the course of a year; they call these the constellations of the zodiac.) And even today, despite so much effort at science education, astrology's appeal for many people has not diminished. For them, thinking of Venus as a cloud-covered desert world as hot as an oven is far less attractive than seeing it as an aid in deciding whom to marry.

Ten Embarrassing Questions

A good way to begin thinking about the astrological perspective is to take a skeptical but good-humored look at the logical consequences of some of its claims. Here are my 10 favorite questions to ask supporters of astrology:

1. What is the likelihood that one-twelfth of the world's population is having the same kind of day?

Proponents of newspaper astrology columns (which appear in more than 1,200 dailies in the United States alone) claim you can learn something about your day by reading one of 12 paragraphs in the morning paper. Simple division shows that this means 400 million people around the world will all have the same kind of day, every single day. Given the need to fill so many bills at once, it is clear why astrological predictions are couched in the vaguest and most general language possible.

2. Why is the moment of birth, rather than conception, crucial for astrology?

Astrology seems scientific to some people because the horoscope is based on an exact datum: the subject's time of birth. When astrology was set up long ago, the moment of birth was considered the magic creation point of life. But today we understand birth as the culmination of nine months of steady development inside the womb. Indeed, scientists now believe that many aspects of a child's personality are set long before birth.

I suspect the reason astrologers still adhere to the moment of birth has little to do with astrological "theory." Almost every client knows when he or she was born, but it is difficult (and perhaps embarrassing) to identify a person's moment of conception. To make their predictions seem as personal as possible, astrologers stick with the more easily determined date.

3. If the mother's womb can keep out astrological influences until birth, can we do the same with a cubicle of steak?

If such powerful forces emanate from the heavens, why are they inhibited before birth by a thin shield of muscle, flesh, and skin? And if they really do and a baby's potential horoscope is unsatisfactory, could we delay the action of the astrological influences by immediately surrounding the newborn with a thin cubicle of steak until the celestial signs are more auspicious?

4. If astrologers are as good as they claim, why aren't they richer?

Some astrologers answer that they cannot predict specific events, only broad trends. Others claim to have the power to foresee large events, but not small ones. But either way astrologers could amass billions by forecasting general stock-market behavior or commodity futures, and thus not have to charge their clients high fees. In October, 1987, how many astrologers actually foresaw "Black Monday" when the stock market took such a large tumble and warned their clients about it?

5. Are all horoscopes done before the discovery of the three outermost planets incorrect?

Some astrologers claim that the Sun sign (the location of the Sun in the zodiac at the moment of birth), which most newspaper horoscopes use exclusively, is an inadequate guide to the effects of the cosmos. These "serious" practitioners (generally those who have missed out on the lucrative business of syndicated columns) insist that the influence of all major bodies in the solar system must be taken into account—including the outmost planets Uranus, Neptune, and Pluto, which were not discovered until 1781, 1846, and 1930, respectively.

If that's the case, what happens to the claim many astrologers make that their art has led to accurate predictions for many centuries?

Weren't all horoscopes cast before 1930 wrong? And why didn't the inaccuracies in early horoscopes lead astrologers to deduce the presence of Uranus, Neptune, and Pluto long before astronomers discovered them?

6. Shouldn't we condemn astrology as a form of bigotry?

In a civilized society we deplore all systems that judge individuals by sex, skin color, religion, national origin, or other accidents of birth. Yet astrologers boast that they can evaluate people based on another accident of birth—the positions of celestial objects. Isn't refusing to date a Leo or hire a Virgo as bad as refusing to date a Catholic or hire a black person?

7. Why do different schools of astrology disagree so strongly with each other?

Astrologers seem to disagree on the most fundamental issues of their craft: whether to account for the precession of the Earth's axis (see the box below), how many planets and other celestial objects should be included, and—most importantly—which personality traits go with which cosmic phenomena. Read ten different astrology columns, or have a reading done by ten different astrologers, and you will probably get ten different interpretations.

If astrology is a science, as its proponents claim, why are its practitioners not converging on a consensus theory after thousands of years of gathering data and refining its interpretation? Scientific ideas generally converge over time as they are tested against laboratory or other evidence. In contrast, systems based on superstition or personal belief tend to diverge as their practitioners carve out separate niches while jockeying for power, income, or prestige.

8. If the astrological influence is carried by a known force, why do the planets dominate?

If the effects of astrology can be attributed to gravity, tidal forces, or magnetism (each is invoked by a different astrological school), even a beginning physics student can make the calculations necessary to see what really affects a newborn baby. These are worked out for many different cases in Roger Culver and Philip Ianna's book *Astrology: True or False* (1988, Prometheus Books). For example, the obstetrician who delivers the child turns out to have about six times the gravitational pull of Mars

The Precession of the Earth:

Are You Reading the Wrong Horoscope?

In addition to its rotation on its axis (giving us our day) and its revolution around the Sun (giving us our year), the Earth has another—more gradual motion—that few people know about. Our planet's axis tips around in a circle, very much like a child's top tends to tip around as it spins. This tipping motion, called *precession*, is quite slow—the Earth's axis takes about 25,000 years to make a full circle.

As a result of precession, the location of the Sun against the background of stars is slowly changing. If the full circle of precession takes 25,000 years and the zodiac circle the sun makes is divided into 12 signs or constellations, it follows that precessions tips the Sun over by one constellation roughly every 2,000 years. Since the rules of modern astrology were set up abut 2,000 years ago, this means that the constellations the Sun finds itself in month by month have shifted over by one.

Let's give a concrete example. Someone born August 1 is considered by astrologers to have Leo as his sun sign. And, indeed, two thousand years ago, the Sun would have been in the constellation of Leo on August 1. But in the 20th century, the Sun is no longer in Leo on August 1 because of precession—instead it is in the constellation of Cancer. The astrological signs and the real constellations are now "out of synch." Since many of the personality characteristics associated with each sign are based on what the constellations looked like to the ancients (a fish or bird, for example), this misalignment certainly calls the whole system of astrology into question. (Actually, some schools of astrology now "correct" for precession, while others gleefully ignore the whole issue.)

and about two thousand billion times its tidal force. The doctor may have a lot less mass than the red planet, but he or she is a lot closer to the baby!

9. If astrological influence is carried by an unknown force, why is it independent of distance?

All the long-range forces we know in the universe get weaker as objects get farther apart. But, as you might expect in an Earth-centered system made thousands of years ago, astrological influences do not depend on distance at all. The importance of Mars in your horoscope is identical whether the planet is on the same side of the Sun as the Earth or seven times farther away on the other side. A force not dependent on distance would be a revolutionary discovery for science, changing many of our fundamental notions.

10. If astrological influences don't depend on distance, why is there no astrology of stars, galaxies, and quasars?

French astronomer Jean-Claude Pecker has pointed out that it seems very small-minded of astrologers to limit their craft to our solar system. Billions of stupendous bodies all over the universe should add their influence to that of our tiny little Sun, Moon, and planets. Has a client whose horoscope omits the effects of Rigel, the Crab pulsar, and the Andromeda Galaxy really had a complete reading?

Testing Astrology

Even if we give astrologers the benefit of the doubt on all these questions—accepting that astrological influences may exist outside our current understanding of the universe—there is a devastating final point. Put simply, Astrology doesn't work. Many careful tests have now shown that, despite their claims, astrologers really can't predict anything.

After all, we don't need to know how something works to see whether it works. During the last two decades, while astrologers have somehow always been a little too busy to conduct statistically valid tests of their work, physical and social scientists have done it for them. Let's consider a few representative studies.

Psychologist Bernard Silverman of Michigan State University looked at the birth dates of 2,978 couples who were getting married and 478 who were getting divorced in the state of Michigan. Most astrologers claim they can at least predict which astrological signs will be compatible or incompatible when it comes to personal relationships. Silverman compared such predictions to the actual records and found no correlations. For example "incompatibly signed" men and women got married as frequently as "compatibly signed" ones.

Many astrologers insist that a person's Sun sign is strongly correlated with his or her choice of profession. Indeed, job counseling is an important function of modern astrology. Physicist John McGervey at Case Western Reserve University looked at biographies and birth dates of some 6,000 politicians and 17,000 scientists to see if members of these professions would cluster among certain signs, as astrologers predict. He found the signs of both groups to be distributed completely at random.

To overcome the objections of astrologers who feel that the Sun sign alone is not enough for a reading, physicist Shawn Carlson of the Lawrence Berkeley Laboratory carried out an ingenious experiment. Groups of volunteers were asked to provide information necessary for casting a full horoscope and to fill out the California Personality Inventory, a standard psychologists' questionnaire that uses just the sorts of broad, general, descriptive terms astrologers use.

A "respected" astrological organization constructed horoscopes for the volunteers, and 28 professional astrologers who had approved the procedure in advance were each sent one horoscope and three personality profiles, one of which belonged to the subject of the horoscope. Their task was to interpret the horoscope and select which of the three profiles it matched.

Introducing Jetology

One good way to get people to think about the validity of astrology is to suggest a similar "science" that is not so weighed down with tradition and history. I like to ask people to consider the new science of *jetology*, which contends that the positions of all the world's jumbo jets at the moment a person is born affect his or her personality and destiny.

To get the full benefit of a jetological reading, a professional jetologer must carefully analyze the pattern of jet positions the world over. (Since a computer will help get the data and organize it, jetology *must* be a scientific discipline!) But even when your jetological chart is finished, a layperson will not be able to make sense of it. Years of training are required to interpret the chart properly. For example, take that bunching of planes over Chicago's O'Hare Airport—its significance for the subject's love life will require a great deal of study by an experienced jetologer.

As your listeners begin to chuckle over the absurdity of this example, you can ask them what makes it so amusing. Someone will surely inquire why the positions of those things in the sky should have anything to do with our lives, and you can then ask the same question about astrology.

Although the astrologers had predicted that they would score better than 50 percent correct, their actual score in 116 trials was only 34 percent correct—just what you would expect by guessing! Carlson published his results in the December 5, 1985, issue of *Nature*, much to the embarrassment of the astrological community.

Other tests show that it hardly matters what a horoscope says, as long as the subject feels the interpretations were done for him or her personally. A few years ago French statistician Michel Gauquelin sent the horoscope for one of the worst mass murderers in French history to 150 people and asked how well it fit them. Ninety-four percent of the subjects said they recognized themselves in the description.

Geoffrey Dean, an Australian researcher who has conducted extensive tests of astrology, reversed the astrological readings of 22 subjects, substituting phrases that were the opposite of what the horoscopes actually stated. Yet the subjects in this study said the readings applied to them just as often (95 percent of the time) as people to whom the "correct" phrases were given. Apparently, those who seek out astrologers just want guidance, any guidance.

Some time ago astronomers Culver and Ianna tracked the published predictions of well-known astrologers and astrological organizations for five years. Out of more than 3,000 specific predictions (including many about politicians, film stars, and other famous people), only about 10 percent came to pass. Veteran reporters—and probably many people who read or watch the news—could do a good deal better by educated guessing.

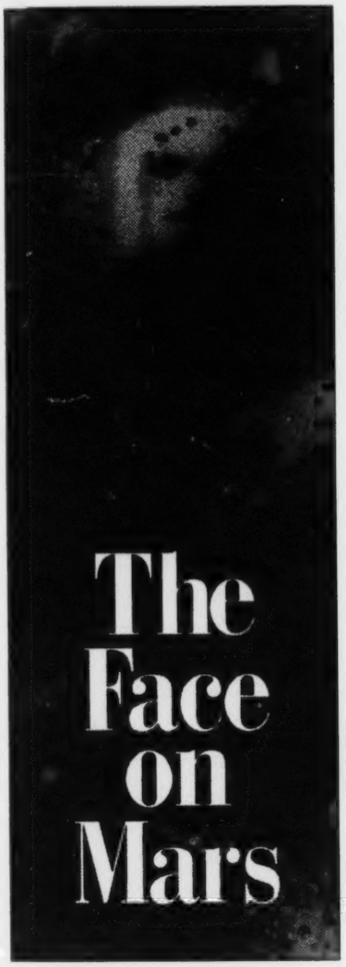
If the stars lead astrologers to incorrect predictions 9 times out of 10, they hardly seem like reliable guides for decisions of life and affairs of state. Yet millions of people, including the former First Lady, seem to swear by them.

Clearly, those of us who love astronomy cannot just hope that the public's infatuation with astrology will go away. We must speak out whenever it is useful or appropriate—to discuss the shortcomings of astrology and the shaky ground it is based on. Those of us working with youngsters can use these ideas to develop a healthy skepticism in the students and encourage an interest in the real cosmos—the one of remote worlds and suns that are mercifully unconcerned with the lives and desires of the creatures on planet Earth. Let's not allow another generation of young people to grow up tied to an ancient fantasy, left over from a time when we huddled by the firelight, afraid of the night.

THE UNIVERSE IN THE CLASSROOM

No. 25-Fall 93

Sponsored by - Astronomical Society of the Pacific - Canadian Astronomical Society - American Astronomical Society - International Planetarium Society



The planet Mars has intrigued humans since we first began to study the sky. It is the only planet that looks red to the naked eye, which may explain why the ancient Greeks and Romans associated it with the bloody god of war. Spacecraft that visited Mars in the '60's and '70's found a freezing, arid, dead world. Nevertheless, the idea of life on Mars, and, in particular, intelligent life on Mars, fed by years of science fiction stories, persists in the public mind, despite the weight of scientific evidence against it.

This myth has surfaced again in the so-called "Face on Mars," a rock outcropping that looks like a human face when lit from the side. Astronomers see it as a mere optical illusion, proof of the power of human imagination. But a few, very vocal individuals see it as proof of an ancient Martian civilization. They even go so far as to accuse NASA of deliberately destroying the billion-dollar *Mars Observer* spacecraft at the end of August to keep from having to admit that the Face is "real." Such extraordinary claims require extraordinary proof, which is sorely lacking in this case. But the Face on Mars is not the first time humans have been misled about evidence for life on our neighboring planet.

The Martian Canals

When early astronomers trained their crude telescopes on Mars, they could see few details of its surface beyond some dark patches and white polar caps. In some ways, the mysterious planet seemed tantalizingly like Earth. A Martian day is only 37 minutes longer than one on Earth. Mars' equator is tilted relative to the plane of its orbit around the Sun by almost the same amount as the Earth's, which gives Mars, like Earth, seasons. And the ice caps on its north and south poles wax and wane with the seasons. By the 1800s, Mars seemed enough like Earth that astronomers and science fiction writers began to dream of a Mars populated with intelligent, alien beings.

In 1877, Mars came within 56 million kilometers (35 million miles) of Earth, about as close as it ever gets (because its orbit is somewhat elongated, its distance at closest approach to Earth varies from year to year). Taking advantage of the close range, American astronomer Asaph Hall discovered two moons circling Mars. Other astronomers strained to learn as much as they could about the red planet. Using the 8-and-3/4-inch refracting telescope at the Brera Observatory in Milan, Italian astronomer Giovanni Schiaparelli reported seeing a network of very fine, regular lines crisscrossing the reddish deserts of Mars. He called them canali, which means "channels" or "grooves," but the word was translated into English as "canals." Given the limited understanding of the Martian atmosphere and climate at the time, and the known similarities to Earth, many people jumped to the conclusion that Schiaparelli's canals had been constructed by intelligent beings.

Percival Lowell, a successful Boston businessman, was so captivated by this idea, that, in 1893, he built a major observatory in the clear skies of Flagstaff, Arizona to study the Martian canals. Lowell was convinced that intelligent Martians had built a network of canals to pump water from the melting ice caps to dying cities in the desert. In 1971, the *Mariner 9* spacecraft sent back to Earth the first really good, high-resolution maps of the planet. Absolutely no canals were seen, and the volcanoes, valleys and craters that were mapped didn't correspond to any feature seen by Lowell.

It turned out there never were any canals on Mars. When straining to look at things that are barely visible, the human eye tends to join faint but distinct markings together. That's what happened to the astronomers struggling to learn more about the surface of Mars. The Martian canals say more about human perception and imagination than anything else. As Carl Sagan said in *Cosmos*, "Lowell always said the regularity of the canals was an unmistakable sign that they were of intelligent origin. This is certainly true. The only unresolved question was which side of the telescope the intelligence was on."

Drawing of Mars, done on October 11, 1916, showing "canals" seen by an astronomer looking through a telescope. Right: Photograph of the Red Planet taken the next evening. (Courtesy Lowell Observatory)

The Face on Mars

A similar statement can be made about the Face on Mars. In 1976 two unmanned *Viking* spacecraft went into orbit around Mars. Each sent a lander down to the surface, while the orbiters radioed back over 60,000 photographs of the Martian surface. Not long after the orbiters began their mission, *Viking* scientists noticed a picture of a squarish, mile-long low hill or mesa in the Cydonia region of Mars that looked sort of like a face. They released the image to the press as a sort of joke, an example of our tendency to see apparently familiar shapes in complex landscapes. The researchers and the press recognized the Face as an unusual rock formation created by weathering. The dramatic low angle of late-afternoon lighting in the photo made the outcropping look like a Face.

Three years later, two computer scientists with no particular expertise in Martian geology working for a contractor at NASA came across the image while going through the *Viking* photo archives. They experimented with some image-enhancement programs and concluded that the Face did not occur naturally. They also noticed several "pyramids" near the Face, and published a book calling attention to the structures.

In the 1980s, Richard Hoagland, a science journalist, took up the cause of the Face on Mars in several books and numerous radio and TV appearances. In the scattered hills of Cydonia, Hoagland sees evidence of a ruined "city" and "fort." He claims the city and the Face are aligned in a way that may have, in the manner of Stonehenge, pointed to the place where the sun rose on the Martian solstice half a million years ago (which Hoagland takes to be when the Face was made), although the orientation has no meaning today. Clearly, to Hoagland, this region of Mars is the result of a gigantic construction project by intelligent beings.

But who were they? And why does the Face look human? Hoagland has several theories. Perhaps evolution worked the same way on Mars as it did on Earth and so the Martians actually looked human. Or maybe a previously unknown, technologically advanced civilization from Earth's distant past traveled to Mars (or, alternatively, an advanced Martian civilization came to Earth long ago, and we look like them). Or perhaps the Face was built by some sophisticated extraterrestrials from beyond the solar system as a signal (or test) for us when we had reached a certain stage of technological evolution (rather like the black monolith in the movie *2001: A Space Odyssey*).

Is the Face Real?

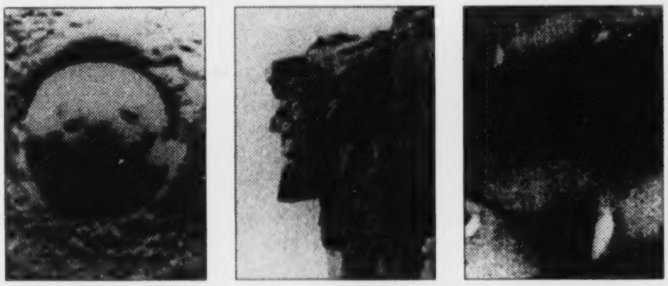
Certainly the rock outcropping on Mars is suggestive of a human face. But that doesn't mean it is a monument deliberately constructed to look like a face. According to psychologists, the human visual system is organized to look for familiar features in random patterns. And there is a particularly strong human tendency to see faces given minimal details. For example, people all over the world see the face of a man when they look at the Moon (others see a rabbit in the Moon). We see animals and human faces in clouds. In New Hampshire, the face of the "Old Man of the Mountain" gazes impassively out from the side of a cliff. We've all seen people in the news or on TV talk shows who have found vegetables or potato chips that look like famous people. Another Viking image shows a Martian crater with what looks like a smiling "happy face" inside. No one thinks any of these were deliberately created, so why should the Face on Mars be any different?

What about the "pyramids" near the Face on Mars? There are a number of small mountains on Mars that resemble pyramids, both in Cydonia and another region called Elysium. Geologists who specialize in desert landscapes are quite familiar with similar wind-sculpted formations here on Earth, for example, in the deserts of Arizona. The "city" on Mars is a cluster of these pyramid-shaped mountains, the biggest a few kilometers at the base, all oriented in the same direction. Carl

Sagan has noted that similar formations, called dreikanters, from a German word meaning three sides, are seen in Antarctica. Strong winds blowing from mostly the same direction over many years turn what were once irregular bumps into nicely symmetrical pyramids. Dreikanters are small, only about knee-high, while the Martian "pyramids" are much taller. But winds on Mars are much fiercer than those on Earth, with wind speeds that can reach half the speed of sound, and it is not unreasonable to suggest that dust storms blown by these strong winds could sculpt larger versions of dreikanters.

The Cydonia region of Mars is dotted with many low hills that have been molded into odd shapes, perhaps by a combination of ancient mudflows and wind erosion. The Face on Mars seems to have been created in the same way as these features, even though they don't look like anything in particular.

The original *Viking* photograph of the Face on Mars is riddled with black dots. These dots correspond to areas where data was lost during the transmission of the picture from the *Viking* orbiter to Earth (such transmission losses are common given the problems of communicating with spacecraft over interplanetary distances). If we look carefully at the original image, we see that a black dot of lost data happens to fall right about where we would expect to see a "nostril" on the Face. This makes the rock look even more like a face, but doesn't correspond to any real feature on the Martian surface.



Left: This Martian impact crater looks like the largest known "Happy Face" in the solar system. The smiling mouth and eyes were formed by fractures caused by the original meteor impact. The main crater is about eight kilometers (five miles) across. (Courtesy NASA)

Center: The "Old Man of the Mountain" in the White Mountains of New Hampshire looks like a face when viewed from the side. (Courtesy Dick Hamilton Photo, White Mountain News Bureau)

Right: "Pyramids" in the Cydonia region of Mars, were most likely sculpted by wind erosion. (Courtesy NASA)

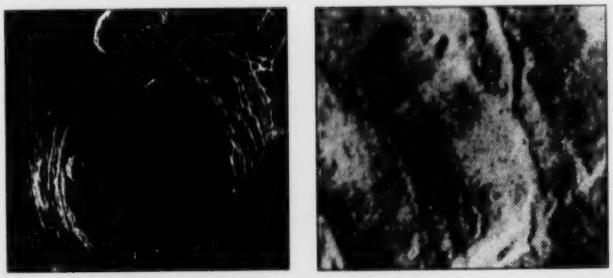
Scientists take great care when interpreting images sent back by spacecraft. When confronted with an alien landscape, it is easy to see what you want or expect to see, not necessarily what is really there. Similar care is needed when interpreting enhanced images. There is only so much information that a picture contains. Image processing or image enhancement will bring out details that were present in the original picture, although not obvious. If you process an image too much, you run the risk that things will appear in the enhanced picture that were not present in the original; such things cannot be believed. This is an issue that astronomers constantly struggle with, given today's emphasis on electronic detectors and computer processing in astronomical research. But it is an issue that is rarely adequately addressed by proponents of the Face on Mars, who depend on enhanced images to back up some of their claims. For example, early proponents claimed to see a "honeycomb" structure on the Martian surface, which they took to be a complex of rooms. Later, the honeycomb was shown to be an artifact of the computer image processing, and not something that was present in the original images. Still, some proponents continue to cite the honeycombs as evidence of a Martian civilization.

And what about the reported alignments of the pyramids and the Face? In order for the alignment to work, Mars' equator would have to be tilted 17.3° relative to the plane of its orbit around the Sun (it is now tipped 24°). It is possible that Mars at one time had such a tilt. But, in this case, there are so many possible variations, with so little to restrict them, that random chance would no doubt produce some apparent alignments. Given that proponents had the freedom to choose any of a number of solar or celestial alignments, any time since the beginning of the solar system, and to move the planet any amount to fit an alignment, the fact that one can be found is not proof that it was intended.

Extraordinary Claims Require Extraordinary Proof

The *Viking* orbiters took only two images that show the Face on Mars. The pictures are of such low resolution and poor quality that they cannot prove conclusively one way or the other whether the Face on Mars is naturally occurring or artificial. One of the guiding principles of scientists is that simple, straightforward explanations of phenomena are more likely to be correct than complicated, convoluted ones. This principle, known as Occam's razor (after the fourteenth century English philosopher, William of Occam, who first proposed it; razor is used in the sense of shaving an argument to its simplest terms), means that if two hypotheses fit the observations equally well, the one that makes the fewest assumptions should be chosen.

Applying Occam's razor to the Face on Mars, we ask which is the simpler explanation: that wind erosion, over millions of years, molded a low hill into a shape that happens to resemble a human face when lit from the side (in the same way that it molded many other odd shapes in the same area), or that technologically advanced, intelligent aliens, who may or may not have looked like us and who left no other evidence of their existence, created a gigantic monument with a human face for an unknown reason? If we can explain the Face on Mars as the product of well-understood geological processes that we know occur elsewhere on the planet, why do we need to invoke unknown alien beings working in an unknown way for unknown reasons to explain it? Out of the 150,000,000-square-kilometer total surface area of Mars, is it so surprising that a tiny one-square-kilometer-sized area looks a little funny?



Left. Fotla Corona, an oval-shaped volcanic feature on Venus, looks rather like the muppet Miss Piggy, minus one ear. The corona formed when a large blob of hot magma rose, created a large bulge in the surface and then sank, collapsing the bulge and leaving a ring that looks like a "fallen soufflé." This feature is 200 kilometers in diameter. The ear and eyes are actually flat-topped volcanic features called "pancake domes." (Courtesy NASA)

Right. This unusual lava flow pattern resembles the muppet Kermit the Frog. It lies on the flank of Alba Patera, a large volcano in the northern hemisphere of Mars. A small impact crater in the flow looks like an eye. (Courtesy NASA)

Mars is a fascinating planet. Its huge volcanoes dwarf those on Earth. Along its equator, a gigantic chasm stretches so far that, on Earth, it would span the entire United States. Perhaps most intriguing are what look like dry river channels that snake across the Martian deserts. Although liquid water cannot exist on the surface of Mars now, evidently some time in the past the atmosphere was thick enough and the temperatures warm enough for pools of water, rivers, rain and floods to scour the Martian surface. The reality of Mars is exciting enough; we don't need artificially created monuments to manufacture interest in the red planet.

We should always remain skeptical of outrageous stories like that of the Face on Mars, unless there is unquestionable evidence to back them up. Like the Rorschach ink blot tests that psychologists use to probe a person's psyche, claims about the Face on Mars tell us more about humanity's desire not to be alone in the universe than about Martian geology.

There is another region on Mars that looks like Kermit the Frog. On the planet Venus, there is a volcanic feature that resembles the face of Miss Piggy (minus one ear). Taken together, and using the same logic as proponents of the Face on Mars, these two features would seem to prove that there once was a group of intelligent aliens who traveled from planet to planet, and worshipped Muppets! Or maybe not. ●

What Happened to *Mars Observer*

On Saturday, August 21, 1993, NASA mission controllers lost contact with the *Mars Observer* spacecraft, one day before it was to enter orbit around Mars and begin a three-year mission to survey and study the Red Planet. Communication was lost after ground controllers had radioed commands to pressurize its fuel tanks in preparation of rocket firings to slow the spacecraft down and allow it to be captured by Mars' gravity.

Initially there was speculation that a problem with the pressurization may have caused the fuel to leak, making the spacecraft tumble out of control, or even explode. After a few days of silence, a second theory emerged: a pair of electronic transistors in *Mars Observer's* master clock, the timekeeper for most of the craft's computers, may have failed, disabling the spacecraft. A NASA task force investigating the loss of *Mars Observer* should release its findings by the end of this year.

What about other missions to Mars? *The Mars Environmental Survey* (MESUR) involves a network of a dozen or more landers. Each lander will have a small mobile robot to explore the Martian surface. The first lander in the network, *MESUR Pathfinder*, is scheduled for launch by NASA in 1996 (to arrive at Mars in 1997). The *MESUR* missions are not dependent on results from *Mars Observer*, and thus should not be affected by its loss.

On the other hand, two planned Russian missions to Mars, *Mars 94* and Mars 96, had hoped to use the *Mars Observer* orbiter to relay data from a lander (in the case of *Mars 94*) and atmospheric balloon (for *Mars 96*) to their orbiters farther away from the planet. At this time it is unclear what effect the loss of *Mars Observer* will have on these missions. NASA scientists are also looking into the possibility of creating a new spacecraft to replace *Mars Observer*, using parts scavenged from other missions. But this replacement won't be ready until November 1996, at the earliest.

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WHAT'S YOUR SIGN?

ACTIVITY K-1

GRADE LEVEL: 6-9

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What's This Activity About?

Astrology is far more present to our students than astronomy may seem to be. Almost every newspaper has an astrology column, and no supermarket checkout counter is immune from the "personal horoscope" displays. Students are interested in their Sun signs, and we can use their interest to help them understand constellations. In addition, astrology can help students understand precession, the slow wobble of the Earth on its axis that has slowly changed the dates corresponding to particular zodiac constellations.

What Will Students Do?

Students sit in a circle holding constellation signs and symbols, and learn why astrological dates no longer correspond with the actual sky.

Tips and Suggestions

- Although designed for a planetarium, this activity can be done in the classroom. Put a light bulb in the center of the circle to represent the Sun. Using an Earth globe, point out daylight and nighttime sides of the planet. Ask students to visualize what "side" of the sky they can see from the nighttime side, and visualize why the constellations behind the Sun—the Sun sign—are not visible in the day time.
- Use a large top to demonstrate precession.

What Will Students Learn?

Concepts

Sun Signs
Stars not visible in the daytime
Precession

Inquiry Skills

Observing
Inferring

Big Ideas

Patterns of Change

Activity 15: What's Your Sign?

Most students are very interested in their astrological sun sign, though very few understand its astronomical significance. You can exploit your students' interests in astrology to help them learn about how and why the constellations change with the seasons, and how the seasonal appearance of the constellations has slowly changed over the past two thousand years because of precession of the earth's axis. The activity uses the technique of having the students model the earth, sun, and constellations with their bodies. Suggestions are also given for helping the students to separate astronomy from the pseudo-science of astrology.

Grade Levels: 6-9

Organization: Individual Task and Small group

Reasoning Level: Concrete to Formal

Activity Strategy: Direct Information and Synthesizing

Behavioral Objectives: By the end of the lesson, students should be able to:

1. Explain the astronomical meaning of their astrological birth sign, or sun sign;
2. Explain why they cannot see their birth constellation on their birthday, and about how long they would have to wait to see it in the nighttime sky.

Older students will also be able to:

3. Define "sign of the zodiac" to be an invisible region of the sky that no longer corresponds to the "constellation of the zodiac" that has the same name.

Materials

13 sheets of white paper, 13 sheets of black construction paper, 13 sheets of light blue construction paper, clear tape or a stapler, a broad marking pen, and material for making stars (such as yellow sticky dots, gold stars, paint, or whiteout). To check student understanding, you may also want to make one copy of the data sheet for each student, and provide pencils and clipboards or other writing surfaces.

Preparation

1. Tape or staple the black and blue sheets so that you have thirteen cards that are blue on one side and black on the other. On each black side make one of the constellations of the zodiac, using yellow stars or dots or paint. Label and number each constellation, as indicated on the master sheet.
2. Place a lamp or yellow ball in the center of the planetarium (above or below the projector) to represent the sun.
3. (Optional, for introducing the effect of precession to older students) On each white sheet, write the name and symbol of one of the constellations of the zodiac, using a broad marker.

Presentation

Ask the students if they know their astrological birth "sign." Most will probably know what it is. Then, ask if anyone knows what the astrological birth sign means in terms of the positions of the sun, moon, and planets when they were born. (Accept their ideas and allow for discussion.) Tell the students that a person's "sign" is a short way of saying their "sun sign," and they will learn what sun sign means in this activity.

Arrange the students in a large circle around the planetarium. Have thirteen students hold the black and blue zodiac constellation signs so they are evenly spaced around the dome. (If doing this in a Starlab Planetarium, have students sitting around the edge of the dome hold the cards.) The order of constellation

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signs should be Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpius, Ophiuchus, Sagittarius, Capricorn, Aquarius, and Pisces. They should hold their cards so the black side with the stars faces towards the center of the room. Turn on the "sun" light in the center of the room.

Explain that in this model of the sky, the sun is in the center, and the zodiac constellations are arranged in a big circle, some unknown distance away. As we know today, the earth goes around the sun.

Ask for a volunteer to represent the earth. Ask her to stand between the sun and the circle of constellations and to walk once around the "sun." Ask the students, "How much time goes by when the earth goes around the sun once?" (One year.)

Now align the earth person so that from her point of view, the sun is blocking out the constellation of Aries. Explain that this is the earth's approximate position during the period April 21 to May 20. Ask the "earth," "What constellation is behind the sun?" (Aries.) Explain that anyone born on the earth at this time is born under the "sun sign" of Aries.

Ask the person to slowly continue in the earth's orbit until the next constellation is obscured by the sun, and to announce when that occurs by saying "Now the sun is entering the constellation of...," and so on for two or three constellations.

Point out that the sun continues to block any given constellation for about one month, since there are twelve zodiac constellations. Anyone born during that month is born under that sun sign. Ask the students, "Can you see your sun sign constellation on your birthday?" (No, the sun is in the way!)

To illustrate and expand on this idea, ask the student who is playing earth, to face towards the sun, and name all of the constellations that she sees. Ask the earth person, "What time of day is it for people who live on the front part of your face?" (Daytime, or noon.) Can these people really see these constellations? (No.) So, each person holding a constellation sign that was named should turn it so that the blue part faces towards the earth.

Ask the earth person to turn slowly until the "sun sets," and the stars come out. As she turns, she can see more and more constellations (each of which should now have their black sides with stars and names facing the earth.) Tell the earth person to keep turning until the sun is behind her. Ask, "What time of day is it now for people who live on the front of your face?" (Nighttime, or midnight.) Ask her to name the constellations that she can see in the night sky. Have that person walk around the sun, and stand in the position of the earth six months later. Again, have daytime constellations turn their blue sides towards the earth, and have the earth turn to observe constellations in the nighttime sky.

To see if the students understand the model, ask them if they can see their birth or sun constellation on their birthdays? (No.) How long would they have to wait to see their birth constellation overhead at midnight? (About six months.) Hand out the data sheet and allow time for the students to answer the questions. Allow some time for discussion of the answers.

Using the planetarium sky, point out a zodiac constellation and ask the students to point out where they would expect another one to be. Reinforce the idea that the zodiac constellations were not chosen because they were bright or easily found, but because the sun appeared to be in front of them. The zodiac forms a line or circle around the sky

To reinforce the students' understanding of astrological signs, ask the students if they can guess what their astrological "moon sign" is. (It is the constellation of the zodiac where the moon was at their birth. Similarly, the "rising sign" or "ascendant" is the sign of the zodiac that was rising on the eastern horizon at the moment when they were born.)

Astrologers divide the sky into only 12 astrological signs (constellations), omitting Ophiuchus. You will never find an astrologer designate anyone's birth sign as Ophiuchus! Astrologers further assume that the sun is in each sign for one month. ***Astronomers***, in contrast, divide the sky into constellations with precise boundaries. The amount of time that the sun is in each constellation of the zodiac is different, being determined by the exact constellation boundaries. The exact times that the sun is in each constellation are given on pages 56-57 in the column "Astronomers' Dates." Notice that astrologers' dates are about one month off!

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Optional: For older students, go on to explain the difference between "sign" and "constellation" as follows: More than 4,000 years ago, when astrology was invented, the sun always lined up with the same constellations on the same dates. However, as hundreds of years went by, astronomers began to notice that the dates when the sun was expected to line up with one constellation slowly changed, so that now, over 4,000 years later, the zodiac constellations have "slipped" one entire constellation. This is now known to be caused by the slow "wobble" of the earth's axis called **precession** (described in more detail in Activity 14: Stars Through the Ages.)

Astrologers, however still judge a person's sun sign according to the ancient dates. This means that a person born between April 21 and May 21 is still said to be born "under the sun sign of Taurus," but on that person's birthday, the sun was actually lined up with the constellation Aries. (The moon sign, rising sign, and other astrological signs are also off by about one constellation.) Thus, the term **sign of the zodiac** has come to mean an invisible area of sky that no longer corresponds to the **constellation of the zodiac** that has the same name. In about 26,000 years, when the earth's axis completes one slow wobble, the signs and constellations of the zodiac will again line up.

Illustrate this idea by handing out white sheets with the symbols and names of the zodiacal signs. Arrange these in a circle, so that the signs are held by students one position to the left of the constellations of the same name, e.g. the sign of Aries will be in front of the constellation of Pisces. Have another volunteer name both the sign and constellation that the sun lines up with in different months. How can we model the way things will be in 4,000 A.D.? (Move the signs one more position to the left.)

Sum up by telling the students that they have just created a model which illustrates the meaning of the "astrological birth sign," or "sun sign." Whether or not they believe in the **pseudo-science of astrology**—which claims that people born under the same astrological sign have certain common characteristics—is up to them. The **science of astronomy** makes no such claim.

The students may be interested to know that several hundred years ago, when most people believed in astrology, many famous astronomers, such as Caudius Ptolomy, Johannes Kepler, and Tyco Brahe, made their living by making astrological predictions. (Your students may want to look up these names in an encyclopedia to find out their contributions to astronomy.) Some modern historians claim that the most important motive for studying astronomy through the ages has been the desire to make more accurate astrological predictions. So, if it were not for the practice of astrology in the past, there might be no science of astronomy today!

The articles below have excellent information on the relationships & distinctions between astronomy and astrology:

Mechler, Gary, Cyndi McDaniel, & Steven Mulloy, "Response to the *National Inquirer* Astrology Study," submitted to *The Skeptical Inquirer*, May 6, 1980. Study done at Northern Kentucky University.

Shapiro, Lee T., "The Real Constellations of the Zodiac," *The Planetarian* (the International Planetarium Society journal), March, 1977, pages 17-18.

Fraknoi, Andrew, "Your Astrology Defense Kit," *Sky and Telescope*, August, 1989, p. 146.

Good articles and classroom activities on debunking astrology may be found in the Universe in the Classroom Newsletter #11, Fall 1988. It is available from Astronomical Society of the Pacific, 390 Ashton Ave., San Francisco, CA 94112, (415) 337-1100.

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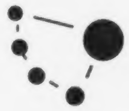
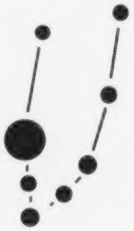
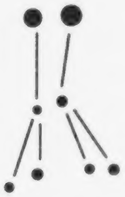
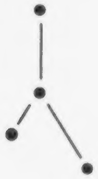
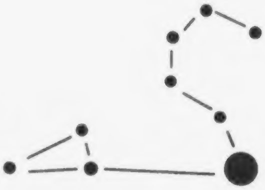
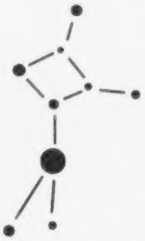
Astrologers' Dates	Constellation	Symbol	Astronomers' Dates
1 Aries March 21 to April 20		♈	Apr 19 - May 13 (25 days)
2 Taurus April 21 to May 21		♉	May 14 - Jun 19 (37 days)
3 Gemini May 22 to June 21		♊	Jun 20 - Jul 20 (31 days)
4 Cancer June 22 to July 22		♋	Jul 21 to Aug 9 (20 days)
5 Leo July 23 to Aug 23		♌	Aug 10 to Sep 15 (37 days)
6 Virgo Aug 24 to Sep 23		♍	Sep 16 - Oct 30 (45 days)

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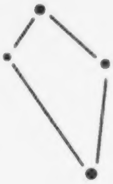
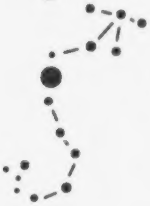
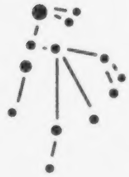
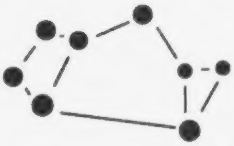
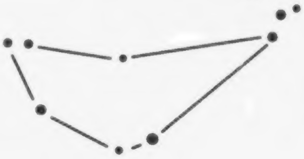
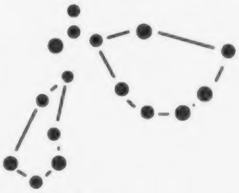
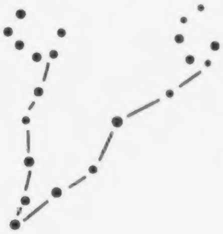
Astrologers' Dates	Constellation	Symbol	Astronomers' Dates
7 Libra Sep 24 to Oct 23		♎	Oct 31 - Nov 22 (23 days)
8 Scorpius Oct 24 to Nov 22		♏	Nov 23 - Nov 29 (7 days)
Ophiuchus Not recognized as a sign of the zodiac by astrologers		**HAS NO SYMBOL**	Nov 30 - Dec 17 (18 days)
9 Sagittarius Nov 23 to Dec 21		♐	Dec 18 - Jan 18 (32 days)
10 Capricorn Dec 22 to Jan 20		♑	Jan 19 - Feb 15 (28 days)
11 Aquarius Jan 21 to Feb 19		♒	Feb 16 - Mar 11 (24 days)
12 Pisces Feb 20 to Mar 20		♓	Mar 12 - Apr 18 (38 days)

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NAME **DATE**

The Zodiac in Day and Night

1. In the picture below, which Zodiac Constellation would be behind the sun as seen from the position of earth in the drawing? ______________________________
2. Which Zodiac Constellation would be seen overhead at midnight for the position of the earth in the drawing? ______________________________
3. Draw the earth in the proper place for your birthday and list the following information:

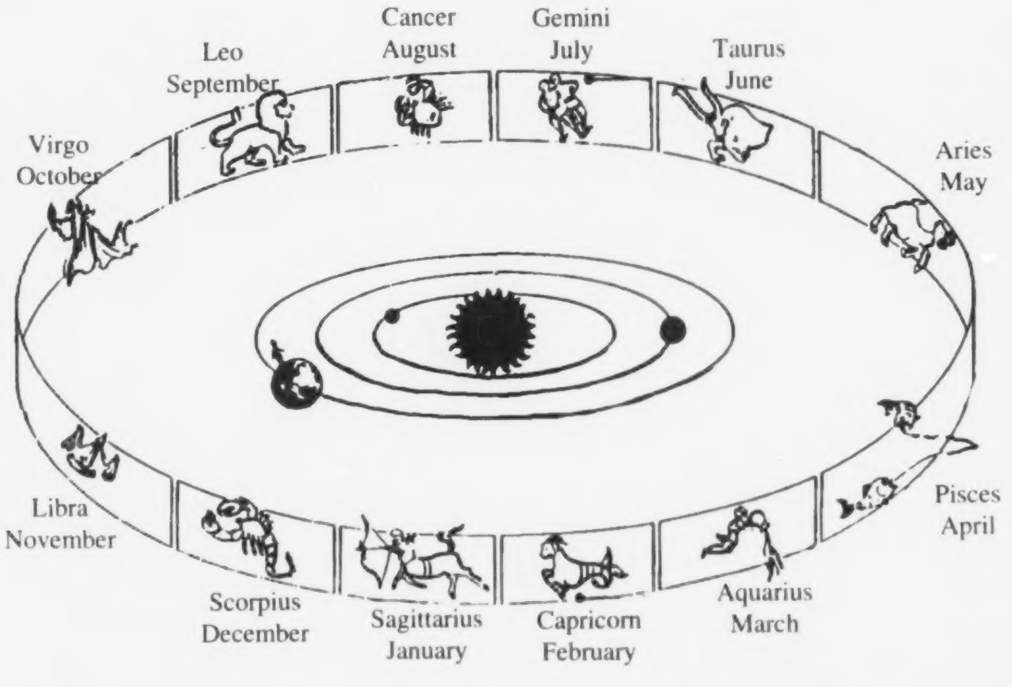
   For my birthday (list date) ______________________________

   a. The Constellation behind the sun is ______________________________

   b. The Constellation overhead at midnight is ______________________________

4. Which constellation in the astronomers' zodiac is missing in the picture below?

   ____


Cancer
August
Gemini
July
Leo
September
Taurus
June
Virgo
October
Aries
May
Libra
November
Pisces
April
Scorpius
December
Sagittarius
January
Capricorn
February
Aquarius
March

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ACTIVITIES ABOUT ASTROLOGY

ACTIVITY K-2

GRADE LEVEL: 7-9+

Source: This activity was written by Andrew Fraknoi, Astronomical Society of the Pacific, 390 Ashton Avenue, San Francisco, CA 94112, (415) 337-1100. Copyright ©1993 by the Astronomical Society of the Pacific. (The activity incorporates suggestions and ideas by Diane Almgren, Daniel Helm, and Dennis Schatz.)

What's This Activity About?

These activities help students to understand the difference between science and pseudoscience by investigating some of astrology's claims. Letting students have a good discussion after working with these activities can be very effective. We encourage you to read "Your Astrology Defense Kit," found earlier in this section, before doing these activities.

What Will Students Do?

Students test the validity of astrology by charting birthdates of U.S. presidents, and by comparing horoscopes in different newspapers. Finally, students attempt to identify their own horoscope from an unidentified list of daily predictions.

Tips and Suggestions

- Chart Sun sign horoscopes for other famous people like U.S. senators, world leaders, or actors, who might be expected to have common personality characteristics.
- The final activity, where students try to identify their own horoscope from an unidentified group of horoscopes, works especially well with larger groups of students.
- If you plan to do this activity with a class, get the school library to order the books suggested in advance. (Most school libraries will not have these.)

What Will Students Learn?

Concepts

Astrology's basis in archaic constellation positions
Disproving a scientific theory

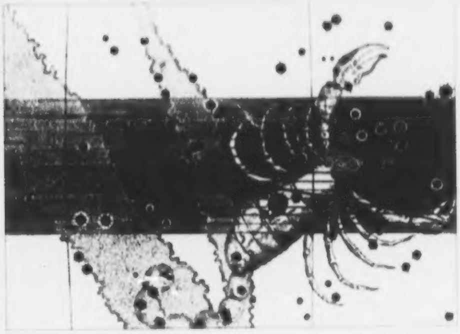
Inquiry Skills

Predicting
Inferring
Reasoning
Recognizing Bias

Big Ideas

Diversity and Unity

Activities About Astrology



by Andrew Fraknoi

Foothill College and Astronomical Society of the Pacific

Aims:

These three activities are designed to

1) Help students think critically about the pseudoscience of astrology

2) Become familiar with the kind of statistical testing that scientists do to evaluate hypotheses.

> *"The fault dear Brutus, is not in our stars, but in ourselves..."*
>
> *Shakespeare's Julius Ceasar, Act I, Scene 2*

These activities incorporate ideas and suggestions by Diane Almgren of Broomfield, CO, Daniel Helm of Phoenix, AZ; and Dennis Schatz of the Pacific Science Center in Seattle, WA.

Activity 1: Testing Astrology with the Birthdays of the Presidents

Astrologers will tell you that the Sun sign (which sign of the zodiac the Sun was in when an individual was born) is a crucial factor for the occupation a person chooses and a strong determinant of overall personality as it relates to one's job. As an example of how we can test such a hypothesis, students can examine the birthdates of the 41 men who have successfully run for the job of President of the United States.

After all, it takes a certain kind of personality to be President (outgoing, well-spoken, ambitious). If personality and occupation are strongly affected by Sun sign, we should find that the birthdays of the Presidents are clustered in one (or a few) signs. If Sun signs do not affect personality and occupation, the Presidents' birthdays should be randomly distributed among the zodiac signs.

Have students used the attached worksheet to determine the astrological signs of the 41 Presidents and discuss their results. You will need to review the concept of random distribution before doing this activity.

When students are done with the worksheet, discuss how many Presidents we would expect to find under each sign if the birthdays of the 41 Presidents were randomly distributed among the 12 signs of the zodiac. Since there are 41 people, chance would classify 3.4 people (41÷12 = 3.4) into each of 12 random "bins." (With only 41 data points, you might expect one or two fewer or one or two more Presidents in a given sign.)

As an extension, you might encourage students to discuss other (and better) ways to test this hypothesis. What occupations are also personality-driven but have more than 41 people in them? (As discussed in *Your Astrology Defense Kit* earlier in this section, one group of statisticians tested all the men who re-enlisted in the Marine Corps—definitely a personality related career choice!)

Testing Astrology with the Birthdays of the Presidents

Student Worksheet

1. George Washington:	Feb. 22, 1732
2. John Adams:	Oct. 30, 1735
3. Thomas Jefferson:	Apr. 13, 1743
4. James Madison:	Mar. 16, 1751
5. James Monroe:	Apr. 28, 1758
6. John Q. Adams:	July, 11, 1767
7. Andrew Jackson:	Mar. 15, 1767
8. Martin Van Buren:	Dec. 5,1782
9. William Harrison:	Feb. 9, 1773
10. John Tyler:	Mar. 29, 1790
11. James Polk:	Nov. 2, 1795
12. Zachary Taylor:	Nov. 24, 1784
13. Millard Fillmore:	Jan. 7, 1800
14. Franklin Pierce:	Nov. 23, 1804
15. James Buchanan:	Apr. 23, 1791
16. Abraham Lincoln:	Feb. 12, 1809
17. Andrew Johnson:	Dec. 29, 1808
18. Ulysses Grant:	Apr. 27, 1822
19. Rutherford Hayes:	Oct. 4, 1822
20. James Garfield:	Nov. 19, 1831
21. Chester Arthur:	Oct. 5, 1830
22. Grover Cleveland:	Mar. 18, 1837
23. Benjamin Harrison:	Aug. 20, 1833
24. William McKinley:	Jan. 29, 1843
25. Teddy Roosevelt:	Oct. 27, 1858
26. William Taft:	Sep. 15, 1857
27. Woodrow Wilson:	Dec. 28, 1856
28. Warren Harding:	Nov. 2, 1865
29. Calvin Coolidge:	July 4, 1872
30. Herbert Hoover:	Aug. 10, 1874
31. Franklin Roosevelt:	Jan. 30, 1882
32. Harry Truman:	May 8, 1884
33. Dwight Eisenhower:	Oct. 14, 1890
34. John Kennedy:	May 29, 1917
35. Lyndon Johnson:	Aug. 27, 1908
36. Richard Nixon:	Jan. 9, 1913
37. Gerald Ford:	July 14, 1913
38. Jimmy Carter:	Oct. 1, 1924
39: Ronald Reagan:	Feb. 6, 1911
40. George Bush:	June 12, 1924
41. William Clinton:	Aug. 19, 1946

1. Which sign do you predict will have the greatest number of Presidents?

2. How many Presidents' birthdays fall under each of the Zodiac signs?

Aries: ______

Taurus: ______

Gemini: ______

Cancer: ______

Leo: ______

Virgo: ______

Libra: ______

Scorpius: ______

Sagittarius: ______

Capricornus: ______

Aquarius: ______

Pisces: ______

3. Which sign has the largest number of Presidents? How many?

4. Which sign has the smallest number of Presidents? How many?

5. Looking at your results, do you see any patterns?

6. Would you say the birth dates of the Presidents are strongly clustered in one or a few signs?

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Activity 2: Horoscopes from Different Astrologers

In this activity, students compare horoscopes in different newspapers from the same day. Ask students to bring in newspapers or buy them yourself. You can also copy newspapers from a local library, although having photocopies reduce the psychological impact of the activity somewhat. The more newspapers you have, the better the activity.

Cut the horoscope sections out of the papers and distribute them to students. If possible, cut out the horoscopes in full view of the students for greater impact. Ask several students to read aloud the different horoscopes of one or more selected students from the various newspapers. Discuss the following questions:

1) How well do the predictions of different astrologers agree for that student's sign?

2) How specific are the newspaper statements?

3) Could they apply to a lot of different people?

4) In what ways could the statements apply to different people?

Have the students discuss some reasons why the predictions in astrology columns might be so general and vague. If there's time, continue the discussion by bringing up some of the "embarrassing questions about astrology" in *Your Astrology Defense Kit* (elsewhere in this section).

Activity 3: Mixed-up Horoscopes

In this activity, students try to find their own sign from a variety of unidentified signs in a horoscope column. Use an astrology column from a recent newspaper (today, yesterday, or last weekend). It is best to use an out-of-town newspaper so students are not likely to have seen it. Cut out the horoscopes and remove the dates, signs, and any telltale references to the sign, like, "you're a real lion at times." Be sure to make a copy of the full column for yourself and put it aside. Mix up the order of the descriptions, and give each one a number from 1 to 12. Transfer these numbers to your copy for future reference.

Have each student write down his or her name and birthday on a piece of paper. Distribute the sheet with all the numbered (but otherwise unlabeled) horoscopes to the students and have them select the one description that best fits the day in question. (Be sure you remind them of the day the horoscopes apply to.)

Ask students to predict how they think this experiment will turn out. To prevent sudden changes of answers, ask students to exchange papers at this point. Then put the signs and birthdates associated with each numbered paragraph on the board. Have the class count how many students picked their own sign among the 12 and how many did not.

If Sun sign astrology predicts one's day pretty well and everyone remembers the day in question clearly (the astrologer's hypothesis), students should in general be able to find their own paragraph. But if chance instead of the stars governs the composition of those descriptions (the skeptic's hypothesis), we would expect that only one out of 12 of the students would have selected the description for their own signs.

Warning

With small numbers of students in one class, it often happens by chance that there are a few more correct picks than one would expect by chance. With older students, this can give you a chance to discuss the need for large samples in good statistical studies. If students get intrigued by such extra bits, one way to check is to extend the test to other students or school staff.

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UFO DETECTIVE

ACTIVITY K-3

GRADE LEVEL: 4-9+

Source: This activity was written by Andrew Fraknoi, Astronomical Society of the Pacific, 390 Ashton Avenue, San Francisco, CA 94112, (415) 337-1100. Copyright ©1993 by the Astronomical Society of the Pacific.

What's This Activity About?

This activity helps students to approach media stories about UFOs with the healthy skepticism of a scientist who looks for alternative explanations and proof before ascribing a particular explanation to the phenomena. The activity treats UFO incidents as detective stories, where students search for clues and scientific explanations among the many claims.

What Will Students Do?

First students discuss their knowledge of UFOs, and how a detective might investigate claims of UFO sightings or contact. Then students are encouraged to investigate particular incidents using the library or other reference sources. Finally, students come together as a group to discuss other explanations for UFO incidents, and the motivations behind some UFO claims.

Tips and Suggestions

- Tie this activity to lessons about the search for extraterrestrial intelligence. See the *Space Exploration and SETI* section for more ideas.

What Will Students Learn?

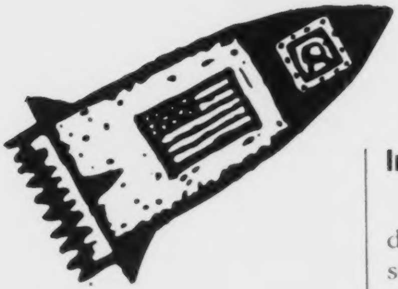
Concepts
- UFO incidents as publicity stunts
- Astronomical objects mistaken for UFOs
- Skeptical reasoning

Inquiry Skills
- Evaluating
- Communicating
- Inferring
- Recognizing Bias

Big Ideas
- Interactions

UFO Detective

by Andrew Fraknoi
The Astronomical Society of the Pacific



Aims:

This activity is designed to:

1) develop thinking skills

2) encourage students to use the library for research; and

3) help students take a skeptical attitude towards newspaper or television reports of UFO's

Introduction:

In many ways, the job of a scientist is similar to that of a detective (an occupation which is among those most frequently seen on television, and therefore very familiar to most students). A detective (like Colombo or the stars of the recent series *Law and Order*) is usually called to the scene of the crime after the criminal has fled, and must piece together what happened from eyewitness reports and clues that were left behind. Witnesses may not remember shocking events correctly; sometimes their imaginations embroider the story of what happened with fanciful details. Other witnesses will lie to protect themselves or make themselves look good. Some of the clues left at the scene will be helpful and others may be misleading. It may occasionally happen that there is no corpse or direct evidence of the crime: perhaps it turns out to be a misunderstanding or a hoax. Yet, no matter how little or how much there is to go on, a good detective will sort through all the information and piece together one or more hypotheses for what happened—which can then be tested against all the evidence to determine which is most likely, thereby solving the crime.

Astronomers can be thought of as "sky detectives"—piecing together clues to events and objects located far away and long ago. Like the scene of an ancient crime, some of the clues are "cold" and hard to read. Others, like the spectrum of a star or galaxy, are full of good information, but need to be sorted out carefully to see what may be relevant to the questions at hand. An astronomer needs to sift through all the clues to come up with hypotheses about what is happening "out there." Often, an astronomer will see something new in the sky that will be unfamiliar, and will have to fit his or her observations into the scheme of what we already know about the universe. Or, in a leap of imaginitive thought, she may need to come up with an entirely new explanation. Just like the detective who must determine which person is the most likely suspect based on the evidence, the astronomer must consider and weigh the evidence in deciding which hypothesis provides the best explanation for the observation.

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The Activity

This activity consists of three separate parts, which can be done together or spread out over the school year. The level of sophistication with which each part is done should be appropriate to the grade level and skills of your students.

Part One: Class Discussion

Introduce the topic by having students discuss their own knowledge of UFO's. Although an occasional student may have seen what they thought (or others told them) was a UFO, for the most part their "experience" with UFO's will have been acquired completely from the media—especially television. Have them discuss what kinds of UFO reports and claims they have heard about and classify them into different categories, such as: lights in the sky versus landings and abductions; or events seen by many people vs. those seen by a single individual.

Then begin a discussion of how a detective might go about investigating a UFO report, considering the categories one at a time. What sort of evidence would a detective gather or look for? What would you want to find out about the witnesses and their reliability? Which different hypotheses would explain the sightings? (Such hypotheses might include fireballs—rocks from space burning up in the Earth's atmosphere—high-flying aircraft, hoaxes, and other scenarios besides alien spacecraft.) What would you need to make a solid case to support one hypothesis over the others? Some teachers like to break up the students into small groups at this point. If the students can do so, get them to agree on a protocol for such an investigation. In any case, after their initial discussion, suggest that they might next want to compare their suggestions to the ways people who have spent their lives being "UFO detectives" investigate UFO's.

Some of the instincts and training of a detective or a scientist are very useful skills for students to acquire—whether for sorting out conflicting claims of political campaigns, controversies about health and medical treatments, or claims of the paranormal (such as psychic powers, pyramid power, or regular visits by alien spaceships.) In this activity, we will examine how detective work can help evaluate the evidence about claims that Unidentified Flying Objects (UFO's) are spaceships from extraterrestrial civilizations that come to Earth regularly, and even occasionally kidnap human beings (as is so often shown in the media).

Part Two: The Research

Give each group a famous UFO case to research (see the attached student worksheet for descriptions of a few famous cases with useful references to read. These references describe many other useful cases as well.) Some teachers like to give each group the same case, but many prefer to give a different case to each group. Have each group report back (orally and/or in writing) on what the initial ideas were when the case was first reported, and what the investigation revealed. The reporting students

Background for Teachers UFO Explanations:

Jimmy Carter's UFO

The investigator found a remarkably simple explanation for the brilliant celestial object the president-to-be had observed: it was the planet Venus.

The Travis Walton Case

Careful investigation showed the entire case to be a hoax, perpetuated by the wood-cutting crew to prevent them from being fined for being late with the job.

The Betty and Barney Hill Case

Careful investigation showed the entire incident to be in Betty Hill's troubled mind, but the film inspired a whole spate of copy-cat abduction stories.

The Roswell Incident

In fact, the debris was a classified balloon to search for evidence of nuclear tests whose origin was our own planet. See the attached news report for the full story.

may enjoy taking on the identity or personality of a detective while describing how his or her group "solved" the case. (Some groups have become so interested in their cases, they have gone on to make a poster display for the school library.)

Younger students may simply want to read about UFO's in general. Two excellent books for them are: Alschuler, W. *UFO's and Aliens.* 1991, Avon Books; and Asimov, I. *Unidentified Flying Objects.* 1989, Gareth Stevens.

Part Three: The Applications

Have students discuss (either in their groups or as a class):

1. "UFO" stands for "Unidentified Flying Object" (or more properly, an unidentified object in the sky). Some people say that "UFO's can't possibly exist!" Do you agree with this statement? Why or why not? (If the student's can't think of it, you might suggest that a UFO report is merely a piece of evidence, which may be explained by a variety of different hypotheses. The report exists, but a good detective will not jump to a conclusion before all the evidence is in.)
2. What "earth-bound" explanations might be found for other types of UFO reports? (See the books on the attached resource sheet for some of the explanations UFO detectives have found in the past.)
3. Why might people want to create a hoax or publish things they know are not true when it comes to UFO's? (Money and publicity are a big lure.)
4. Why would a "detective attitude" be helpful for a scientist?
5. Where else in life might the "detective attitude" be useful to apply?

Famous UFO Cases

JIMMY CARTER'S UFO

When he was still governor of Georgia, Jimmy Carter saw and reported (in writing) seeing a UFO. Veteran UFO investigator Robert Sheaffer tracked down the facts of the case, and found a remarkably simple explanation for the brilliant celestial object the president-to-be had observed. What did he find? (See: Book 5 below, Chapter 2.)

THE TRAVIS WALTON CASE

In 1975 a young wood-cutter in Arizona named Travis Walton (who was part of a work crew that was seriously behind on their contract) claimed to have been kidnapped by a UFO. The "incident" was recently made into the film *Fire in the Sky*. What did investigators discover about this case? (See: Book 2, Chapters 18-23; Book 3, Chapter 3; Book 4, Chapter 15.)

THE BETTY AND BARNEY HILL CASE

In 1961 a couple named Betty and Barney Hill drove back late at night from a vacation and later claimed that they discovered, under hypnosis, that during their drive they had been kidnapped by a UFO. Their story became the basis of a book and the 1975 made-for-TV movie, *The UFO Incident*. What did UFO detectives discover about this famous case? (See: Book 1, Chapter 23; Book 3, Chapters 1 & 2; Book 4, Chapters 11 & 15; Book 5, Chapter 5.)

THE ROSWELL INCIDENT

In July 1947, the remains of a flying craft were recovered at the Army Air Force base near Roswell, New Mexico. Since then, rumors have been rife that it was a crashed flying saucer, news of which was quickly hushed up by the government. There was even talk, without any foundation, that alien bodies had been recovered. What is the most likely hypothesis for what really happened? (See: Book 2, Chapter 30; Book 4, Chapter 16 and the attached sheet.)

BOOKS ABOUT THESE CASES:

1. Klass, P. *UFO's Explained*. 1974, Vintage paperback.
2. Klass, P. *UFO's: The Public Deceived*. 1983, Prometheus Books.
3. Klass, P. *UFO Abductions: A Dangerous Game*. 1988, Prometheus Books.
4. Peebles, C. *Watch the Skies: Chronicle of the Flying Saucer Myth*. 1994, Smithsonian Press.
5. Shaeffer, R. *The UFO Verdict: Examining the Evidence*. 1981, Prometheus Books.

Wreckage in the Desert Was Odd but Not Alien

by William J. Broad

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A mysterious 1947 crash in the New Mexico desert that became legendary among flying-saucer fans and cover-up theorists turns out to have involved something nearly as strange as an alien spaceship.

The wreckage, quickly whisked away by the Air Force, was part of an airborne system for atomic-age spying that was invented by a leading geophysicist and developed by Columbia University, New York University and the Woods Hole Oceanographic Institution, according to an Air Force report on the once-secret project as well as principals in the espionage effort.

The program was called Project Mogul, and its goal, set by a postwar America wary of losing its atomic monopoly, was to search high in the atmosphere for weak reverberations from nuclear-test blasts half a world away.

The debris, found near Roswell, N.M., was a smashed part of the program's balloons, sensors and, of most consequence to the growth of spaceship theories, radar reflectors made of thin metal foil.

At the time, the Air Force said the wreckage was that of a weather balloon, a white lie. But over the decades, the incident grew to mythic dimensions among flying-saucer cultists, who spun slim evidence into weighty charges while touting conspiracy theories in scores of books, articles and television shows.

The United States, they said, had possession of alien bodies and otherworldly gear that was incredibly thin and strong. The government, they charged, made death threats to keep knowledgeable people quiet. It studied extraterrestrial craft to learn the secrets of making stealth bombers and fiber-optic communications networks. Roswell was the greatest of all governmental cover-ups.

On September 8th, after an eight-month investigation, the Air Force issued a report and a number of thick appendices that to all appearances deflate the conspiracy theory once and for all. Of course, ardent flying-saucer fans contend that the cover-up continues.

"This won't lay it to rest," Col. Albert C. Trakowski, retired, who as an Air Force officer had run Project Mogul, said with a sigh in an interview. "The psychology is simple: People believe what they want to believe. In New Mexico, flying-saucerism has become a minor industry. There are whole museums dedicated to the presentation of outrageous fictions."

The story of Project Mogul and its repercussions was pieced together from the Air Force report and a host of supporting documents, as well as from interviews with Mogul officials and scholars who study the history of atomic espionage.

The spying system was the brainchild of Dr. Maurice Ewing, a geophysicist who during World War II worked at Woods Hole, on Cape Cod, and later founded a premier earth science research center, the Lamont-Doherty Earth Observatory of Columbia University. His work at Woods Hole involved naval research on the underwater transmission of sound, which, scientists were discovering, can extend thousands of miles. It turned out that waters of differing temperatures, salinities and pressures acted like guides to bounce sound waves between layers over long distances.

It occured to Dr. Ewing in 1944 that the Earth's atmosphere might harbor a similar sound channel at its upper edge, in the tropopause, the transition zone between the troposphere and the stratosphere. After the war, he proposed a surveillance system to the Air Force, which seized on it as a possible way to monitor distant nuclear blasts. Having detonated the world's first atomic bomb in 1945, the United States feared that the Soviet Union might soon succeed as well.

In 1946, Project Mogul was given a top-secret classification with the highest priority. Based at the Air Force Watson Laboratories in Red Bank, N.J., the project hired many prominent scientists and academic institutions to develop the gear. Dr. Ewing and Columbia University, where he had moved, were involved in developing low-frequency sensors. Dr. Athelstan F. Spilhaus, a prominent meteorologist at New York University, was in charge of developing high-altitude balloons that would stay at a constant height. Woods Hole helped interpret test results.

The project at first used neoprene meteorological balloons. Later it pioneered the use of polyethylene balloons, which today remain an important tool of high-altitude research because their transparency lessens solar heating and the up-at-day, down-at-night cycle that such heating imposes on balloons. Project Mogul had the polyethylene balloons manufactured in Mamaroneck, N.Y., and in Minneapolis. Test flights of sensing gear were launched from such places as Lakehurst, N.J., Bethlehem, Pa., and Alamogordo, N.M.

Readings high above the earth were radioed to ground stations. Early test flights, before Mogul developed its own sensors, carried naval underwater sound sensors.

"Money was no object," Colonel Trakowski said. "We seemed to have an unlimited budget."

The New Mexico work was the most extensive. Numerous balloon flights carried both sensors and, to aid tracking, radar reflectors. To the untrained eye, the reflectors looked extremely odd, a geometrical hash of lightweight sticks and sharp angles made of metal foil.

B-29 bombers, bomb-toting balloons and ground sites at the White Sands proving ground in New Mexico detonated high explosives for sound-monitoring experiments. The project also eavesdropped on American nuclear blasts in the Pacific, including the Sandstone series of 1948.

The Soviets detonated their first nuclear bomb in August 1949. Mogul detected it, most experts interviewed about the program said. But by that time it was clear that the work was doomed. The main problem was high-level winds that often pushed the balloons out of range of radio communications with the ground. The project was ended in late 1950.

"Operationally it was a nightmare, but scientifically it was a great success," Dr. Charles B. Moore, Mogul's project engineer and now an emeritus professor of atmospheric physics at the New Mexico Institute of Mining and Technology, in Socorro, said in an interview.

Colonel Trakowski added that the visible nature of the system, with its squadrons of big balloons, had abetted its demise. "It was like having an elephant in your backyard," he said, "and hoping that no one would notice it."

A final reason, said Dr. Charles A. Ziegler, a Brandeis University historian writing a book on atomic-age spying, was that Government research showed that sound waves from distant blasts could be monitored on the ground. The United States, he added, now runs such a system around the globe. Details of it are a top national secret.

Although Mogul disappeared into dim Federal corridors, its fallout did not. Its debris littered the New Mexico countryside. According to the Air Force, it was just such debris that fell to earth in 1947 outside Roswell and sowed the seeds for decades of confusion.

Since the Roswell debris no longer exists, the Air Force cannot prove that it was from Project Mogul. But photographs of it, taken in 1947 and published in newspapers, show bits and pieces of what are obviously collapsed balloons and radar reflectors."The relatively simple description of sticks, paper, tape and tinfoil has since grown to exotic metals with hieroglyphics and fiber-optic-like materials," the Air Force report says. "Bodies of extraterrestrial aliens were supposedly retrieved."

Books devoted to the subject include: "The Roswell Incident," "The U.F.O. Crash at Roswell," "The Roswell Report" and "The Truth About the U.F.O. Crash at Roswell." It was considered by flying-saucer devotees the best U.F.O. case of them all, the most thoroughly investigated and authenticated.

The groundswell eventually reached the Washington offices of Representative Steven H. Schiff, Republican of New Mexico, who early this year asked the General Accounting Office, the investigative arm of Congress, to press the Pentagon to declassify documents relating to Roswell. That, in turn, led to the Air Force report, which Air Force Secretary Sheila E. Windall ordered to be as thorough as possible.

"Back then the Air Force had to protect top-secret information," said Lieut. James McAndrew, an investigator who worked on the report. "But after 47 years it's good to stop taking a black eye."

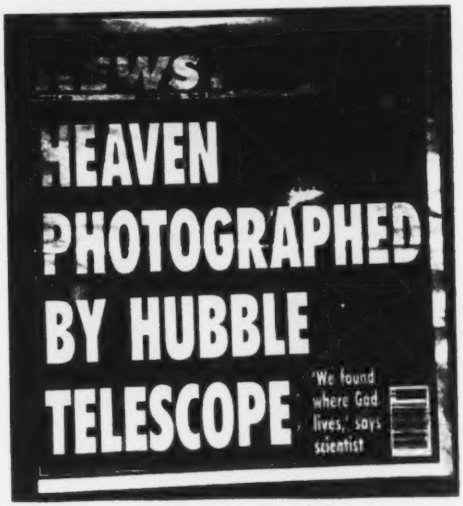
NEWS
HEAVEN PHOTOGRAPHED BY HUBBLE TELESCOPE
'We found where God lives,' says scientist

Photo Courtesy of Weekly World News

RESOURCES FOR EXPLORING ASTROLOGY AND OTHER ASTRONOMICAL PSEUDOSCIENCES

by Andrew Fraknoi
Astronomical Society of the Pacific
390 Ashton Avenue
San Francisco, CA 94112

Books and articles marked with a • are especially useful for those just becoming familiar with the subject.

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

On Astrology

• Culver, R. & Ianna, P. *Astrology: True or False?* 1988, Prometheus Books. The best skeptical book about astrology, by two astronomers.

• Fraknoi, A. "Your Astrology Defense Kit" in *Sky & Telescope*, Aug. 1989, p. 146. A lighthearted review of the skeptical perspective.

Kelly, I. "The Scientific Case Against Astrology" in *Mercury*, Nov/Dec. 1980, p. 135. A good overview article.

Abell, G. "Astrology: Its Principles and Relation and Nonrelation to Science" in *Science Teacher*, Dec. 1974, p. 9.

Dean, G. "Does Astrology Need to be True?" in *The Skeptical Inquirer* Magazine, Winter 1986-87, p. 166 and Spring 1987, p. 257.

Kurtz, P., et al. "Astrology and the Presidency" in *The Skeptical Inquirer*, Fall 1988, p. 3. On the controversy surrounding the use of astrology in the Reagan White House.

Lovi, G. "Zodiacal Signs Versus Constellations" in *Sky & Telescope*, Nov. 1987, p. 507.

On UFO's

Klass, P. *UFO's Explained*. 1974, Vintage; *UFO's: The Public Deceived*. 1983, Prometheus Books; *UFO Abductions: A Dangerous Game*. 1988, Prometheus Books. A senior aerospace editor takes a clear skeptical look at specific UFO reports and finds a lot less there than at first meets the eye; these are the best resources on UFO cases.

Shaeffer, R. *The UFO Verdict: Examining the Evidence*. 1981, Prometheus Books. A good review by an active — and skeptical — UFO investigator.

Peebles, C. *Watch the Skies: A Chronicle of the Flying Saucer Myth*. 1994, Smithsonian Institution Press. Excellent history and analysis of UFO's and their popularity.

Goldsmith, D. & Owen, T. "Visitors to Earth: A Skeptic's Guide to UFO's" in *Mercury*, Jul/Aug. 1992, p. 135 and Sep/Oct. 1992, p. 155.

Ridpath, I. "Debunking Astronomical UFO's" in *Astronomy*, Dec. 1988, p. 114.

On the "Face" on Mars

Sagan, C. "The Man in the Moon" *Parade Magazine*, June 2, 1985, p. 12. Debunking the so-called "Face on Mars."

Golden, F. "Facing Up to Mars" in *Discover*, Apr. 1985, p. 92.

Heard, A. "Face-off" in *Air & Space*, Jun/Jul. 1991, p. 22.

Morrison, D. "Seeing Faces on Mars" in *Skeptical Inquirer*, Fall 1988, p. 76.

On Other Astronomical Pseudosciences

Goldsmith, D., ed. *Scientists Confront Velikovsky*. 1977, Norton.

Krupp, E., ed. *In Search of Ancient Astronomies*. 1978, Doubleday. Last section debunks von Daniken and others.

Nickell, J. & Fischer, J. "The Crop-Circle Phenomenon: An Investigative Report" in *The Skeptical Inquirer*, Winter 1992, p. 136 (vol. 16, no. 2).

Rotton, J. & Kelly, I. "The Lunacy of It All: Lunar Phases and Human Behavior" in *Mercury*, May/June 1986, p. 73.

Sagan, C. "White Dwarfs and Little Green Men" in *Broca's Brain*. 1979, Random House. On Sirius B and the Dogon tribe.

On Astronomical Pseudosciences in General

Abell, G. & Singer, B., eds. *Science and the Paranormal*. 1981, Scribners. An excellent anthology of skeptical articles on a variety of borderline areas.

Frazier, K., ed. *Paranormal Borderlands of Science* (1981). *Science Confronts the Paranormal* (1986). *The Hundreth Monkey* (1991). Three collections of articles from *Skeptical Inquirer* Magazine, and published by Prometheus Books.

Ridpath, I. *Messages from the Stars*. 1978, Harper & Row. This book is mainly about life elsewhere, but includes good sections debunking UFO's, ancient astronauts, an African tribe knowing about Sirius B, and other astronomical "fiction science."

Sagan, C. "Night Walkers and Mystery Mongers: Sense and Nonsense at the Edge of Science" in *Broca's Brain*. 1979, Random House. A good discussion of the psychological roots of belief in pseudoscience.

SELECTED READINGS FOR STUDENTS

Ruchlis, H. *How Do You Know It's True?* 1991, Prometheus Books. Discusses the differences between science and superstition and tries to get youngsters to think skeptically.

Asimov, I. & Walz-Chojnacki, G. *UFO's: True Mysteries or Hoaxes?* 1995, Gareth Stevens. A very nice picture book, debunking the idea of UFO's as extraterrestrial visitors.

The Editors of *Odyssey*: "The Face on Mars" in *Odyssey*, 1991, issue #9, p. 12.

Sprungman, B. "What's That on Mars? Let's Face It" in *Odyssey*, Dec. 1993, p. 35.

Krumanaker, L. "Oh Horror-Scopes!" in *Odyssey*, Dec. 1993, p. 22. On astrology.

NOTE: *The Skeptical Inquirer* magazine is published by the Committee for the Scientific Investigation of Claims of the Paranormal. See under addresses in the *Resources & Bibliographies* section of this Notebook.

L

ASTRONOMY IN DIFFERENT CULTURES

644

ACTIVITIES INCLUDED IN ASTRONOMY IN DIFFERENT CULTURES

ACTIVITY	ESTIMATED GRADE LEVEL											
Grades	1	2	3	4	5	6	7	8	9	10	11	12
L-1. Create a Constellation Students learn the definition of a constellation, design their own from a common pattern of stars, and create a short myth.				■	■	■	■	▨	▨	▨	▨	▨
L-2. Stories in the Stars Students view constellation pictures and listen to myths about the constellation Corona Borealis and the stars of the Big Dipper.	■	■	■	■	■							
L-3. Ancient Models of the World Students read how four ancient cultures explained the motions of the Sun and sky, and then create their own story, or cosmology, and share it with others.				■	■	■	■	■	■	▨	▨	▨
L-4. The Astronomical Tourist: An Activity about What and Where in the World to Visit Students investigate the history and modern astronomical science of different geographical areas and plan trips to those areas for groups of people interested in astronomy.							▨	▨	■	■	■	■
L-5. Teaching with Stories and Symbols Students create and color sun symbols from various cultures and retell myths using felt cut-outs.	■	■	■	■	■	■						

■ - Grade levels recommended by authors ▨ - Can be extended to these grade levels.

About the Activities:

Astronomy in Different Cultures

KEY IDEAS IN "ASTRONOMY IN DIFFERENT CULTURES"

- The roots of astronomy are both ancient and broad—reaching back in time to the builders of Stonehenge, and around the world from China to South America.
- A multi-cultural approach provides a realistic picture of the origins of astronomy; communicates astronomical phenomena and how people came to understand them; helps students to correct some of their misconceptions; and allows students from diverse ethnic backgrounds to recognize contributions of their own cultural traditions to astronomy.
- The *Benchmarks* recommends: At the 9-12 grade level, as students study science and mathematics, they should encounter some of the cultural and historical roots of the concepts they are learning. As they study the history of the different periods, cultures, and episodes, students should find that science, mathematics, and invention often played a central role.
- By the time students graduate from 12th grade, they should know that the early Egyptian, Greek, Chinese, Hindu, and Arabic cultures are responsible for many astronomical and mathematical ideas and inventions.
- The activities in this section help students understand how astronomy arose in different cultures at different times; and how these various cultural traditions eventually led to the science of astronomy practiced today.

The roots of astronomy are both ancient and broad—reaching back in time to the builders of Stonehenge, and around the world from China to South America. The methods that archaeologists, ethnographers, and others have used to uncover early astronomical observatories provide fascinating and insightful glimpses into the processes of science. In addition, the stories about each culture that they have uncovered are fascinating and valuable in themselves. These include the

Babylonians' abilities to predict the positions of the Sun and Moon and eclipses, Mayan knowledge of the cycle of Venus, and observations of the solstices at Stonehenge in England and at Machu Picchu in Peru.

A multi-cultural approach to teaching astronomy is valuable from several points of view. First, it provides a realistic picture of the origins of astronomy at many different places in the world. Secondly, historical information about astronomical discoveries communicates both the phenomena and how people came to understand them. Thirdly, many common misconceptions among students today are similar to ideas that were held by ancient peoples. For example, the idea that the Earth is round and not flat was gradually developed over thousands of years. By learning how ancient people came to accept the spherical earth concept, students can unravel some of their own misconceptions. Last but not least is that a multi-cultural approach to teaching astronomy offers a rich diversity of role models for students from different ethnic backgrounds.

The *Benchmarks for Science Literacy* supports both a historical approach and a multi-cultural perspective in teaching science: At the 9-12 grade level, "science and history can support each other more elaborately. As students study science and mathematics, they should encounter some of the cultural and historical roots of the concepts they are learning. As they study the history of the different periods, cultures, and episodes, students should find that science, mathematics, and invention often played a central role." (*Benchmarks*, page 18.)

By the time students graduate from 12th grade, they should know that "Progress in science and invention depends heavily on what else is happening in society, and history often depends on scientific and technological developments ... The early Egyptian, Greek, Chinese, Hindu, and Arabic cultures are responsible for many scientific and mathematical ideas and technological inventions ... Modern science is based on traditions that came together in Europe about 500 years ago. People from all cultures now contribute to that tradition." (*Benchmarks*, page 19.)

The activities in this section are intended to help students understand how astronomy arose in different cultures at different times, and how these various cultural traditions eventually led to the science of astronomy practiced today.

CREATE A CONSTELLATION

ACTIVITY L-1

GRADE LEVEL: 4-7

Source: Reprinted by permission from *Astro Adventures,* by Dennis Schatz and Doug Cooper. Copyright ©1994 by the Pacific Science Center. No reproduction of this activity of any sort is permitted without written permission from Pacific Science Center. Order *Astro Adventures* from Arches Gift Shop, Pacific Science Center, 200 Second Ave. N., Seattle, WA 98109-4895, (206) 443-2001. Book order form provided in the *Resources & Bibliographies* section of this notebook.

What's This Activity About?

This activity is a good start to explore the idea of astronomy as a *human* subject, studied by people everywhere. If you ask most students to name a constellation, chances are they will say, "The Big Dipper" (which is really part of Ursa Major) or perhaps "Orion." The images of a bear or hunter may not be easily pictured by students, and many will wonder how the stories and myths associated with those stars really arose. This activity helps students understand the origin of images and myths for certain star groups, created by different cultures.

What Will Students Do?

Students first learn the definition of a constellation, and then design their own from a pattern of stars. Students create a short myth to explain their constellation, and then share their pictures and stories. Then students can discuss how other cultures around the globe viewed that same group of stars, which we know as Ursa Major.

Tips and Suggestions

- When sharing stories from other cultures, describe who told the myths, what time of year the stars would be visible, where in the sky those stars appeared, and how the people wove their cultural traditions into their stories. The stories often make even more sense when integrated with the appearance of the constellation during a particular season.
- See the *Star Finding and Constellations* section for related activities.
- Do this activity with other constellations. The *Box of Stars* by Catherine Tennant which contains 32 constellation cards with approporately-sized pin holes is a good resource (available from the educational catalog of the Astronomical Society of the Pacific). Other sources of constellation myths are mentioned in Andrew Fraknoi's Bibliography at the end of this section.
- Additional myths about Ursa Major are included in the next activity in this section, "Stories in the Stars."

What Will Students Learn?

Concepts

Constellations
(visible to different people on Earth)

Inquiry Skills

Imaging
Communicating
Explaining

Big Ideas

Patterns of Change

CREATE A CONSTELLATION

For centuries, people in all parts of the world have looked at the stars. The patterns remind them of familiar objects or characters from stories. Different cultures have associated mythological creatures and stories with different constellations of stars.

This activity allows students to create their own constellations and stories from a given pattern of stars, and compare them to what other cultures have seen in the same pattern.

CONCEPT

Constellations are stars that have been grouped to suggest important cultural objects, animals, story characters, or people.

OBJECTIVES

Students will:

- define the term *constellation* as a pattern made from a group of stars.
- use a common pattern of stars to design a constellation.
- write a short myth about their constellation.

MATERIALS

Create a Constellation pattern
overhead transparency of Create a Constellation pattern
pencil
blank paper

PROCEDURE

Advanced Preparation:
Make copies of the Create a Constellation star pattern sheet for each student. Make an overhead transparency of the Create a Constellation pattern.

1. Ask students to name some constellations they've heard of or observed. Discuss with them how they think the constellations got their names. Define the term *constellation*.

2. Distribute copies of the Create a Constellation pattern to each student. Have students observe with the star pattern from any and all possible directions.

3. Have students draw figures or objects using some or all of the stars in the star pattern.

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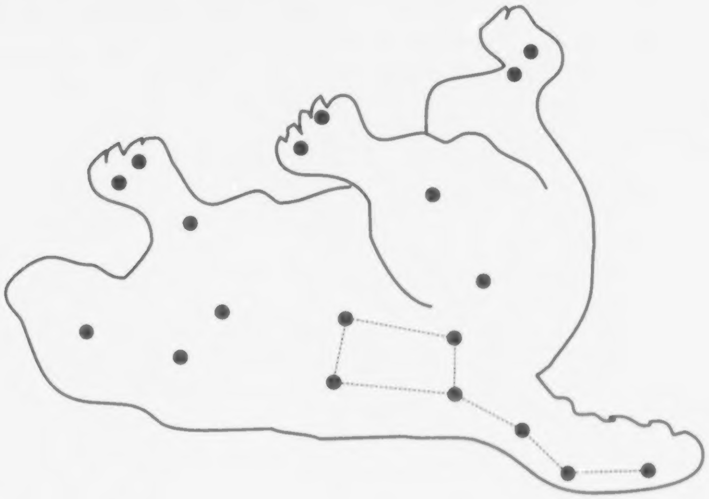
4. Have students write brief stories about their figures and how they came to be found in the stars.

5. Share student-created stories and drawings to emphasize how different people see different figures in the same pattern. The students' stories and drawings can be posted on the bulletin board or put together in a class book.

6. Relate to the students that just as different people in the class saw different figures in the star patterns, so have various cultures when looking at the stars in the night sky. The pattern of stars on the Create a Constellation sheet represent an actual star pattern visible in the night sky.



7. Using the overhead projector, show students where the Big Dipper is found in the Create a Constellation star pattern. This pattern is actually the constellation of Ursa Major. (Astronomers do not consider the Big Dipper as its own constellation because it is part of a larger group of stars.) If possible, draw the rest of the illustration of the bear.

8. Read stories from different cultures based upon this same star pattern. Students may wish to illustrate these cultural stories using the Create a Constellation pattern sheet.

9. Have students research other constellations. Try to find different cultural stories and myths for the same star group.

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URSA MAJOR MYTHS FROM AROUND THE WORLD

GREEK

The god Zeus often changed himself into various animals to carry out his plans upon mortal women. To hide the nymph Callisto from the wrath of his wife, Hera, Zeus changed her into a bear. This saved Callisto from Hera's anger, but introduced her to other dangers—now earthly hunters could take her for a common bear and attempt to kill her. One hunter, named Actas, saw the bear Callisto, drew his bow and prepared to shoot her. Now this was an awful situation, made more terrible by the fact that Actas was the son of Callisto. To prevent Actas from killing his mother, Zeus placed them together in the sky as the Big and Little Bear. According to Ovid, Zeus swung the creatures by their tails to do this, and that accounts for the fact that both Big and Little Bears happen to have abnormally long tails.

According to another Greek myth, the sky is made of soft, pliable glass. Nailed to this glass is a bearskin, held in place by seven nails. The seven points make up the Big Dipper.

In another tale, Zeus became angry at a poor earthly bear, picked it up by its tail, twirled it over his head, and tossed it into the sky.

To Homer, this constellation was both a bear and a "wain" (a wagon). He placed the bear upon the shield of Achilles, described in detail in one of the books of the *Iliad*.

IROQUOIS INDIANS

Once upon a time in a strange and distant land (New York State), some Indians were chasing a bear through the forest. The Indians ran into three giants who, angered by the chase, attacked and killed all but three of the Indians. Suddenly, the three surviving Indians and the bear were transported into the sky, where the chase continues to this day. The bear is formed by the four stars in the cup of the dipper, and the three stars in the handle represent the three Indians. The one closest to the bear carries a bow to shoot the bear, the next one carries a pot to boil the bear in, and the last Indian carries wood to light the fire. The Indian who carries the pot is the star Mizar, and his pot is Mizar's faint companion star, Alcor.

ZUNI INDIANS

For most of the year, the great bear guards the western lands from the frozen gods of the north. In the winter, however, the bear goes into hibernation, leaving the land to be ravaged by the frozen breath of the ice gods. The bear wakes in spring—his growling is to be heard in the spring thunder—and drives the frozen gods back to the north, where they belong.

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HOUSATONIC INDIANS

The big bear hibernates every winter in the cave known to the Greeks as the Corona Borealis. Three Indian warriors find the bear asleep and attack it. The bear wakes up in agony and takes off in a mad dash across the sky, with the three Indians in hot pursuit. It is the tableau of this chase that we see when we gaze into the sky—the four stars on the cup form the bear and the tail stars are the three Indian warriors. The chase lasts for quite some time; finally, around October, the Indians catch up with their quarry. The lead Indian takes his spear and stabs the bear. Although the creature doesn't die, it bleeds profusely and the blood falls out of the sky and onto the leaves of the trees. And that's why leaves turn bright red in the fall.

BASQUE

Once upon a time in the land of the Basques, a man was robbed of two oxen by two thieves. Enraged, the man sent his servant, his housekeeper, and his dog out to chase the thieves and recover the oxen. After a long wait, the man lost his patience and chased after the thieves himself. As punishment for his impatience, the man was taken up into the sky with all the other elements of the story. The first two stars in the cup of the dipper are the two oxen, the other two stars are the two thieves; in the handle of the dipper are the servant, the housekeeper, and the master, who is the final star. The dog is the faint star Alcor.

CHINESE

Chinese astronomers called this constellation the "Jade Balance of Fate." Chinese peasants called it the "Grain Measure."

ARABIAN

The Arabians saw a coffin and mourners in this constellation. The coffin is formed by the four stars of the dipper's cup; the mourners, sons of the deceased, are the three stars in the handle. The three stars here are following the North Star seeking vengeance, for it is that star that killed their father.

GERMAN

To the Germans, who had much first-hand experience with bears, this constellation was not a bear. It was a "Grosse Wagen" (big wagon).

ENGLISH

King Arthur was said to live in the portion of the sky marked by the Big Bear. This conception became transferred in later times to "King Arthur's Chariot" slowly circling the pole. The Irish refer to this group of stars as "King David's Chariot."

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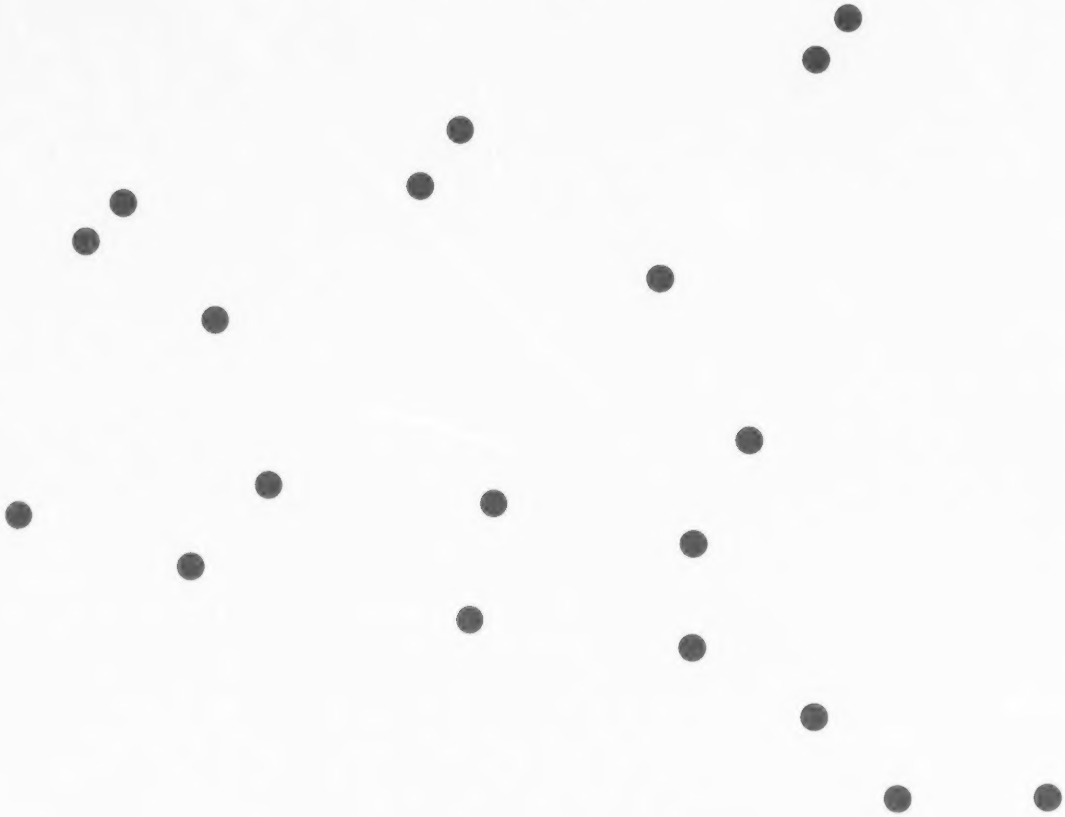
CREATE A CONSTELLATION



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STORIES IN THE STARS

ACTIVITY L-2

GRADE LEVEL: K-5

Source: Reprinted by permission from the National Wildlife Federation from *Ranger Rick's NatureScope: "Astronomy Adventures."* Copyright ©1992 by the National Wildlife Federation, 1400 16th Street, NW, Washington, DC 20036-2266. To order, call (800) 432-6564 from 8am to 11pm, Monday through Saturday. TDD Hearing Impaired Number: (800) 435-3543. "Stories in the Stars" originally appeared in *Once Upon a Starry Night*, by the Hansen Planetarium, Salt Lake City, UT (out of print).

What's This Activity About?

Regardless of where humans live, their skin color, or their customs, they all share the stars. Every culture on Earth seems to tell stories about the constellations. This resource shares information about the images and myths created by different cultures to describe the constellations they saw. It is included in part because its source, *Astronomy Adventures* from the National Wildlife Federation, is an excellent resource for earlier grades.

What Will Students Do?

Students see or make models of the Corona Borealis and Big Dipper, and listen to stories about those constellations.

Tips and Suggestions

- Slides of the constellations will help students to see the images, as will overhead transparencies made from templates like those in *The Box of Stars* described in the preceding activity, and in other activities in the *Star Finding and Constellations* section of this notebook.
- Another source of myths that is especially enjoyable for younger students comes on audio cassette tapes, told by Lynn Moroney. Her *American Indian Star Tales* series incorporates myths from different Indian Nations.
- *Note:* The Big Dipper stars shown in the margin of page 56 of the activity are not correctly aligned to the seasons listed. Use a star and planet locator, planisphere, or other seasonal star chart, or the "Star Clocks" activity, to help identify the correct orientation.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Constellations	Imagining	Patterns of Change

Stories in the Stars

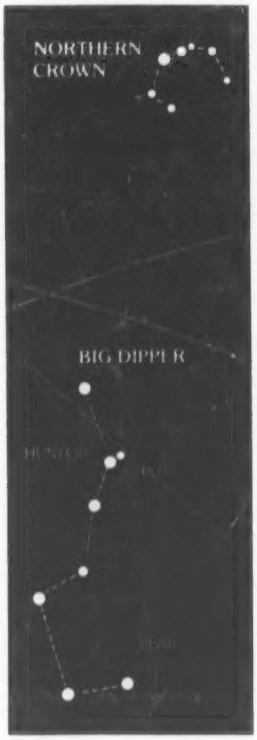
Listen to an ancient Indian myth about the stars and then illustrate it.

Objective:
Explain why constellations were often an important part of religion and folklore.

Ages:
Primary and Intermediate

Materials:
- ***black construction paper***
- ***white stick-on stars***
- ***markers or crayons***
- ***drawing paper***
- ***chalkboard or easel paper***

Subjects:
Science and Social Studies



In many ancient cultures, star watching played an important part in religion and mythology. As people looked at the night sky, they saw patterns and shapes formed by the stars. Not knowing what stars were or how the universe "worked," they often made up myths and stories to explain what they saw. In this activity your kids will learn about how different cultures have viewed stars and then listen to an Indian myth about the Big Dipper.

To start off the activity, ask if anyone knows the names of some common constellations. To show the kids what a constellation is, draw the Northern Crown (below) on the board or on a large piece of easel paper. Explain that this constellation appears in the sky very close to another constellation called Ursa Major. Also explain that a well-known group of stars called the Big Dipper is part of Ursa Major. Now pass out a sheet of black paper and seven stick-on stars to each child. Have the kids paste the stars down in the pattern you've drawn. Then ask if anyone thinks these stars form a shape or pattern.

Explain that the Northern Crown has been the subject of many stories told by people in many different cultures. But not all of the cultures saw it as a crown. Here are some of the ways people have described this group of stars:

Ancient people living in England saw the Crown as the castle of their moon goddess, Arianrhod. These people thought that the open part of the shape was the castle's door that turned through the night to keep enemies from coming inside. (Explain that the constellation appears to rotate during the night, the opening turning in a circle from dusk to dawn.)

The Shawnee Indians in North America believed that the constellation was an open circle of dancing sisters. The gap in the circle represented a missing sister who was carried off by a hunter named White Hawk. White Hawk disguised himself as a field mouse to get close to the sisters, and then grabbed the youngest one. The sister fell in love with White Hawk, but still wished to return to the sky and dance with her sisters. White Hawk finally gave her a white hawk's feather that allowed her to travel back and forth from Earth to the sky in a silver basket. The gap is still in the circle though, because she is not always dancing with her sisters.

Aborigines of Australia saw the Crown as a boomerang, which they used for hunting and in sports. The stars not only form the shape of a boomerang, they also move in a curved path, just as a real boomerang does.

After talking about the Northern Crown, explain that myths about the stars tell a lot about what was important to the people who made them up. Most constellations and other star groupings were of animals or heroes that were part of the peoples' religion, mythology, or daily lives. Explain that many cultures made up stories about the stars to explain why the stars appear to move, why they change position from season to season, why people and animals behave as they do, and many other things.

Tell the kids they're going to be listening to an Indian myth about the group of stars we call the Big Dipper. Explain that this myth is just one of many star stories told by woodland Indians that lived in the eastern part of North America. (Many other cultures have also told stories about the Big Dipper.) Draw the Big Dipper and the Northern Crown on a chalkboard or

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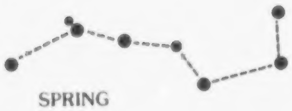
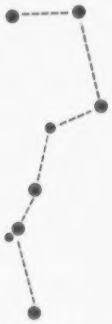
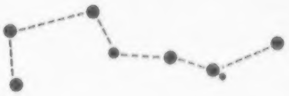


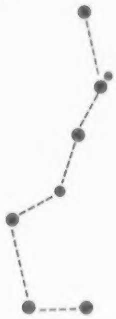
SPRING



SUMMER



FALL



WINTER

large piece of easel paper. (Include the labels shown in the diagram.) Explain that to these Indians the four stars that make up the bowl of the Dipper represented a bear. (Point to the four stars that mark the bear.) The three stars behind the bear represented three hunters. And the star next to the second hunter represented a pot the hunters were carrying so they could cook the bear once they caught it. (Point to the star marked the "pot.") As you read the myth, have the kids act out the movements suggested in parentheses.)

BIG BEAR IN THE SKY

Late one spring, a bear woke up from its long winter sleep and wandered out of its rocky hillside den. (Point to the Northern Crown, the bear's den. In the spring, the Crown is "above" the Dipper and so the bear moves "down.") It was very hungry after its long sleep, so it walked here and there, looking for food. (Have the kids slowly pat their thighs with their hands to imitate the walking bear.) Soon three hunters spotted the bear and started chasing it. (Have the kids slap their thighs quickly.) Just like the bear, all of the hunters were hungry after the long, cold winter. The first hunter carried a bow and arrow to kill the bear, the second one carried a pot to cook the bear in, and the third hunter tagged along behind the others, collecting wood for the fire that they would make so they could cook the bear.

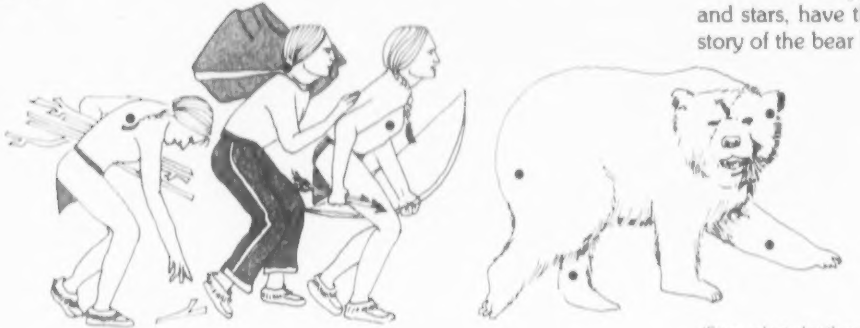
All summer the hunters chased the bear through the sky. (Have the kids keep patting their thighs.) In fall, the bear started to get weak and the first hunter shot it with an arrow. (Have the kids pretend to shoot an arrow.) The arrow killed the bear and it fell over on its back. (In fall, the Big Dipper is upside down in the sky. See diagram.) Blood fell out of the sky from the dead bear and splashed over the leaves of maples, sumacs, and other trees. And that's why we see brilliant red leaves on some trees in the fall.

The hunters ate the bear and left its skeleton behind. As fall turned to winter the weather became colder and colder (have the kids shiver) and the bear's skeleton was still visible in the sky. But the life spirit of the bear had entered a new body—the body of another sleeping bear. (Point to the den again.)

All through the long, cold winter the bear slept. (Have the kids pretend to sleep.) When spring came around again, the bear woke up and lumbered out of its den to search for food. Once again, it was hunted and killed. And its life spirit entered the body of another sleeping bear in the den. And so it happens every year.

Now explain that this story tells a lot about these Indians and what was important in their lives. They hunted to find their food and knew that the positions of the stars changed from season to season. And they used stories such as the Big Dipper myth to explain happenings in nature, such as why leaves turn red in fall.

To finish off your discussion of myths and stars, have the children illustrate the story of the bear hunt.



(Story adapted with permission from the booklet "Once Upon A Starry Night" produced by Hansen Planetarium, Salt Lake City, UT 84111.)

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ANCIENT MODELS OF THE WORLD

ACTIVITY L-3

GRADE LEVEL: 4-9

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What's This Activity About?

We have grown up with an image of the Earth as a planet, circling our Sun, a star, and accounting for the daily motions of the Sun, Moon, and stars with the Earth's rotation. That image—our internal model—has been shaped by countless pictures of Earth from space, from pictures in books, from science classes. We might never even stop to ask the simple question, "Where does the Sun go when it sets in the west?"

Yet many of our younger students will *not* know the answer to this question, and even if they do, most will not know how different societies answered that question in the past. People at different locations on Earth, with different cultures, might have answered with a completely different image of the Earth and Sun. One of the strengths of "Ancient Models of the World" is the imaginative spark ignited in our students as they think about explaining the Sun's motion to others.

What Will Students Do?

Students read about and discuss the celestial models of four ancient societies from Egypt, India, Asia, and Greece, and how each explained the motions of the sky. Then students create their own model for the Sun's motion across the sky.

Tips and Suggestions

- Incorporate art, creative writing and history into the activity. Have students illustrate the models described in the activity and that they create.
- The final part of the activity describes how historical information about the geography and peoples of the areas can supplement each culture's cosmology.
- Have students create large wall murals depicting their models. Ask groups to act out the myths that accompany their Earth/Sun model.
- Use as an introduction to an astronomy unit. The activities in *Our Moon's Phases and Eclipses* follow nicely.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Cultural cosmologies	Imagining Describing Explaining Comparing	Patterns of Change

Activity 1: Ancient Models of the World

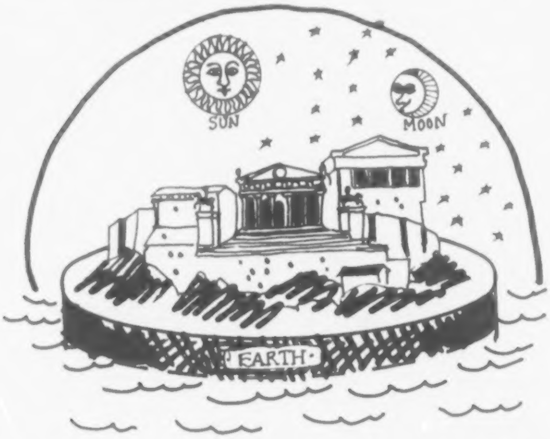
Introduction

Even from a high mountain, the Earth *looks* flat. So it is natural that most ancient models of the world did not portray the Earth as round.

In this first activity, your students compare four ancient models of the Earth. They learn how each of these models explained common events seen daily in the sky, such as the Sun rising in the east and setting in the west. Your students then invent their own "ancient models" of the world.

The process of creating models leads to a much deeper understanding of how they are used in science than does a model designed by someone else. Your students will learn that the science of astronomy began when people started comparing different models to see which ones were most helpful in explaining what they saw in the sky.

Your students will also learn that these early models of the world evolved from ancient myths, passed on to later generations in stories and art. The parts of this activity which describe and illustrate these myths address learning objectives in language and art, as well as science.



Thales' idea of the world in 500 B.C.
"The earth is like a cork bobbing in the sea."

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Time Frame

Part I: Models of the World	40-90 minutes
Part II: Presentations	40-90 minutes

Part I takes about 40-50 minutes if the final drawings are assigned as homework, and closer to 90 minutes if these drawings are completed in class. The length of Part II depends on the number of students in your class, and how much time you allow for each pair of students to present their ideas.

What You Need

For each pair of students:

- ☐ 2 copies of the "Ancient Models of the World" activity sheet (master included, page 7)
- ☐ 1 large sheet of paper or cardboard
- ☐ crayons or magic markers

Getting Ready

Make a copy of the activity sheet for each student and yourself. Familiarize yourself with the models suggested on the activity sheet so you can facilitate the discussion.

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GO!

Part I: Models of the World

1. Ask your students to describe the motion of the Sun in the sky. Most students are aware that the Sun rises in the east, goes overhead, then sets in the west. A few students may be aware that the Sun rises and sets farther to the south in the months October through February, and farther to the north in the months April through August.

2. Ask your students, "After the Sun sets in the west, how does it get all the way over to the east before it rises the next morning?" Encourage several answers.

3. Introduce the term ***model***, defined as a person's explanation for something that has been observed. Your students' explanations for the motion of the Sun are "models" in this sense of the term.

4. Hand out copies of the "Ancient Models of the World" activity sheet. Tell the students that if they had gone to school 3,000 years ago, they might have been taught that *one* of these models was the *only* way to explain observations of the Sun, Moon, and stars.

5. Ask for student volunteers to read aloud the explanations given for each illustration on the activity sheet. Discuss the different explanations and approaches to the same phenomenon—the daily movement of the Sun from east to west. How might these explanations have evolved? How do the explanations reflect the surroundings of the people who created them? [The Egyptians made flat metal plates, and they lived in a river valley. People from India could not get beyond the steep Himalaya Mountains. The Chinese made beautiful rounded and square bowls from ceramic and metal. The ancient Greeks lived on islands, surrounded by the sea.]

Ancient Models of the World

EGYPT

INDIA

CHINA

GREECE

There are many other possible models that could be adapted for this lesson, including stories from Native American and world cultures. Any story that explains or provides a metaphor for the rising and setting of the Sun could be used. The "Literature Connections" section at the end of this guide includes several collections that feature such stories. The GEMS guide Investigating Artifacts has a more extensive list of stories that "explain" natural phenomena, including the movements of the Sun and Moon.

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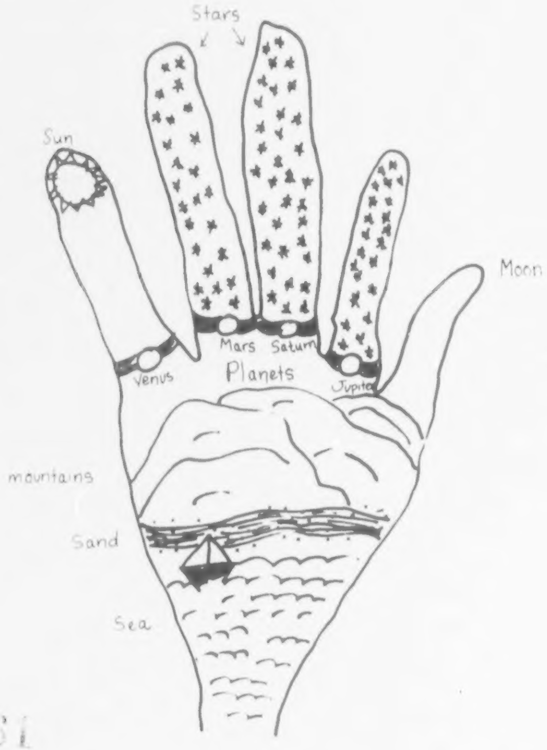
6. Ask the students to imagine that they are living several thousand years ago, on the site where they live now. Challenge them to invent a model of the world to explain how the Sun gets from the western part of the sky back to the east during the night. The model can be a flat Earth or any other shape that might explain the observations. The model can also be designed to explain observations of the Moon and stars.

7. Organize the students into pairs, and hand out scratch paper so they can sketch their ideas. (*Note:* This project can also be done by individuals or small groups.)

8. Give each pair of students a large sheet of white paper or cardboard. Explain that they should draw their ideas of the world so the drawing can be seen by the entire class. Suggest that they label parts of their drawings. If this takes too much time, have the students finish their drawings as homework.

9. When the students finish their drawings, ask them to decide what they will tell their classmates about how their ideas explain the movements of the Sun, Moon, and stars.



Maria and Gina (fifth graders) invented this model and explained, "The people from long ago may have thought that the world was a god's hand. The pointer, middle, and ring fingers were full of stars, and the sun was on the little finger's nail. The moon was on the thumb's nail. The moon would turn back and forth. Sometimes they saw the whole moon or half moon. The planets Venus, Mars, Saturn, and Jupiter were stones on rings. In the morning when the sun came up the three middle fingers would come down and cover the rings."

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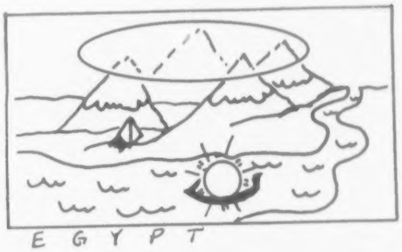
Ancient Models of the World

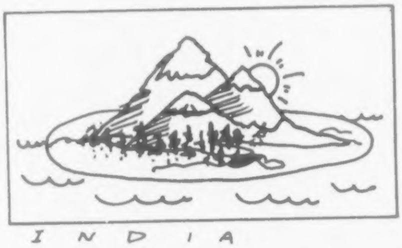
In each of the countries listed on this page, there were many different stories about the world. Here are just a few of those stories.

EGYPT



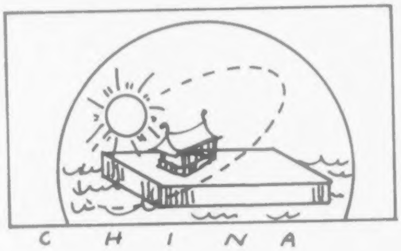
The Earth is flat. The sky is like a flat plate, supported at four places by mountains. The sun is carried across the sky in a boat, from east to west. At night, the sun is carried back to the east through the Underworld.

INDIA



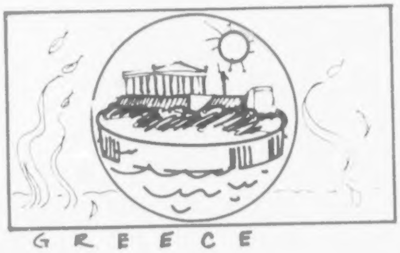
The Earth is a circular disk, surrounded by the ocean. In the center of the world is a great mountain. The sun goes around the mountain once a day. In the evening, the sun goes behind the western side of the mountain. It travels behind the mountain at night, and comes out on the eastern side in the morning.

CHINA



The sky is a round dome, surrounding a flat square-shaped Earth. The ocean goes all around the Earth. The sun travels in a big tilted circle. At night the sun is not under the Earth, but rather on the side of the Earth.

GREECE



Most ancient Greeks believed that the Earth floated in the ocean like a cork in water. One person, named Anaximander, thought that the Earth was a cylinder with a rounded top, floating in the air. The sky surrounded the Earth, and beyond the sky was a region of fire. The sun, moon, and stars were holes in the sky, through which the fire could be seen.

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Part II: Presentations

1. Ask each pair of students to present their ideas. After each presentation, encourage the other students to ask questions. Discuss how well each model explains what we see in the sky.

2. After the student presentations, summarize the lesson by referring to specific examples which show that many different models can be used to explain the same set of observations.

3. You may wish to end the lesson with some additional information about the history of astronomy:

    a. Greece was a center of trade routes, where people from different countries met and exchanged stories about the Earth and sky. Some ancient Greeks listened to these stories and wondered how they could all be true. These people tried to invent models that provided the best explanations for what they saw in the sky. The ball-shaped Earth was one of these ideas, probably suggested by Pythagoras or one of his followers, over 2,500 years ago!

    b. By the time Columbus set sail in 1492, many educated people believed in a ball-shaped Earth. Their biggest disagreement was about its size. Most people thought the Earth was so big that Columbus and his crew would run out of food before they reached land again. In fact, were it not for their unexpected encounter with the Americas, they would have!

The "Mount Nose" activity, described in more detail on page 24, can be done at the beginning of Activity 4, and helps extend and deepen what students have learned in Activity 1 about the rising and setting of the Sun and the ball-shaped Earth.

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THE ASTRONOMICAL TOURIST: AN ACTIVITY ABOUT WHAT AND WHERE IN THE WORLD TO VISIT

ACTIVITY L-4

GRADE LEVEL: 9-12

Source: This activity was written by Andrew Fraknoi, Astronomical Society of the Pacific, 390 Ashton Avenue, San Francisco, CA 94112, (415) 337-1100. Copyright ©1995 by the Astronomical Society of the Pacific.

What's This Activity About?

In most textbooks, the history of astronomy as a science "begins" in Europe with Copernicus, Kepler, and Galileo, or perhaps with the Greeks. But the history of astronomy is not tied solely to Western Europe. Many cultures around the Earth built astronomical observatories, devised accurate celestial calendars, and developed sophisticated mathematics to account for their observations of eclipses, planetary motion, and the seasons. This activity weaves together astronomy, history, and geography, as students investigate the astronomical knowledge of different cultures.

Another strength of this activity is that it incorporates the *current* contributions of other cultures, rather than focusing solely on the past. Students can investigate modern astronomical observatories in distant lands, where important work is taking place today.

What Will Students Do?

Students are asked to plan a trip for a group of people interested in astronomy to a particular area or country. Students investigate the history and culture of that area to locate references about past or current astronomical work, and create an oral or written report.

Tips and Suggestions

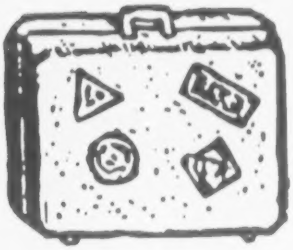
- Do this activity as a month-long research project, group report, or extra-credit assignment.
- Information about some astronomical sites like Stonehenge and the historical achievements of the more famous European astronomers will be easily accessible in an encyclopedia. Other countries with a rich astronomical history, mentioned in the activity, will be more difficult to investigate. Ask the school or public librarian to give students a hand finding sources.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
History of Astronomy	Researching	
Astronomy as a modern, world-wide science	Organizing	
	Communicating	

The Astronomical Tourist: An Activity About What and Where in the World to Visit

by Andrew Fraknoi
The Astronomical Society of the Pacific



Aims

This activity is designed to:

1) Help students understand the contributions of people from other countries and other cultures to astronomy

2) Develop library research skills

The Activity

1. Divide the class into small groups and assign, or have each group select a country or geographic area. Tell students to imagine that they are planning a tour for a group of people who are very interested in astronomy. Where in their country or area would they want the group to visit? Why are these sites important to astronomers? Have students research the astronomical sites in their country or area. They could include historical sites, places where astronomy is currently being done, and museums that teach about astronomy. You may want to have students pick countries that relate to their own ethnic heritage.

2. Have groups create a travel brochure about their area, and give a class presentation. Ask each group member to report on one particular site. You may want to have students write or fax a letter to the embassy or consulate of the country they are researching for information.

Countries to Include

Countries with a rich historical tradition in astronomy include Mexico and Guatemala, Greece, Egypt, Turkey, Persia (now Iran), China, England (where Stonehenge and other stone circles still intrigue visitors), Poland, and Denmark (where Tycho Brahe worked.) Modern astronomical sites can be found in many countries, but especially the US., England, France, Russia, Australia, Holland, Germany, China, Japan, Canada, and Italy.

Some References:

Aveni, A. *Empires of Time: Calendars, Clocks, & Cultures.* 1989, Basic Books.

Cornell, J. *The First Stargazers.* 1981, Scribners.

Hadingham, E. *Early Man and the Cosmos.* 1984, Walker & Co.

Krupp, E. *Echoes of the Ancient Skies.* 1983, Meridian/New American Library.

Kirby-Smith, H. *U.S. Observatories: Directory & Travel Guide.* 1976, Van Nostrand.

Krisciunas, K. *Astronomical Centers of the World.* 1988, Cambridge U. Press.

Marx, S. & Pfau, W. *Observatories of the World.* 1982, Van Nostrand Reinhold.

Tanford, C. & Reynold, J. *The Scientific Traveler.* 1993, John Wiley.

Articles in Sky & Telescope magazine frequently cover astronomical places to visit. For example:

Brunier, S. "Temples in the Sky" Feb. 1993, p. 19; June 1993, p. 26; Dec. 1993, p. 18. Observatory tours.

Shawcross, W. "Venus and the Maya" Aug. 1985, p. 111. Exploring the Yucatan peninsula.

Stott, C. "Greenwhich: Where East Meets West" Oct. 1984, p. 300.

Beekman, G. "The Long Thread of Danish Astronomy" June 1983, p. 487. History and sites to visit.

Blow, G. "Astronomy in New Zealand" June 1982, p. 555.

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TEACHING WITH STORIES AND SYMBOLS

ACTIVITY L-5

GRADE LEVEL: K-6

Source: "Teaching with Stories and Symbols" and "Story Boxes" were developed by Thea Canizo of Project ARTIST at the University of Arizona, Tucson. Reprinted with permission from *Science Scope* magazine, March 1994 issue. Copyright ©1994 National Science Teachers Association, 1840 Wilson Blvd., Arlington, VA 22201-3000. The Sun signs were reprinted with permission from *Indian Designs*, by David and Jean Villasenor. Copyright ©1983 by NATUREGRAPH Publishers, Inc., P.O. Box 1075, Happy Camp, CA 96039.

What's This Activity About?

These three related activities show students that astronomy was important to ancient cultures and other present day cultures. Appropriate for early grades, the activities give students opportunities to decorate Sun symbols from various cultures, and to retell astronomical myths using felt puppets.

What Will Students Do?

Students learn about Sun symbols from different cultures and decorate or create their own to hang in the classroom or bring home. In the third activity, students retell an astronomical myth or legend to themselves, peers, or parents.

Tips and Suggestions

- See the "Skylore Bibliography" at the end of this section for an excellent listing of books containing myths and legends about astronomy.
- Have students create and decorate their own Sun symbols, or make up their own myths.
- The Sun signs, developed by cultures centuries old, like the other designs from *Indian Designs*, are excellent for mulitcultural and bilingual workshops, scouting and classroom projects. These designs can be used in many ways to illustrate skylore or for other crafts projects.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Sun symbols in different cultures	Explaining Imagining	

Teaching with stories and symbols

Create-your-own Sun symbols

Materials

- Sun symbols from various cultures (Figure 1, see page 32 in the following article for information on finding other Sun symbols)
- Construction paper
- Markers or crayons
- Scissors
- Glue

Teacher procedure

1. Introduce the concept of a picture or symbol representing an object.
2. Share pictures of different Sun symbols with students. Discuss the symbols' differences, similarities, importance to the people who designed them, scientific accuracy or lack thereof, and so on.
3. Ask students to design their own Sun symbols by cutting, tearing, and gluing construction paper shapes onto a background color. Discuss the significance of each completed symbol and display the symbols on a bulletin board.
4. Alternatively, allow students to design their symbols on white drawing paper and then paint them on flat, smooth rocks.

Stained glass Sun symbols

Materials

- Cardboard or tagboard backing
- Plastic wrap (preferably Saran Wrap) or transparencies. *Note: Transparencies work best, but are more expensive.*
- Permanent markers
- Masking tape
- Cellophane tape
- Pictures of Sun symbols

Student procedure

1. Choose a Sun symbol to recreate. It can be a symbol discussed in class or one you designed in the previous activity. With masking tape, carefully tape a picture of the symbol by its edges to the desk.
2. Tear off a sheet of plastic wrap several centimeters larger than your cardboard backing. Place the plastic wrap over the Sun symbol and tape its edges to the desk with masking tape.
3. Trace and color the symbol with permanent markers. Note that dark colors and filled-in areas will produce a better overall effect than light colors and fine-line outlining.
4. Tear off a piece of aluminum foil a little larger than the cardboard backing. Crumple the foil, then *carefully* flatten it. The uneven surface will catch the light, creating a stained-glass effect.
5. Lay the foil on top of the cardboard backing and fold the edges around the back. Carefully lift the plastic wrap from the desk, remove the tape, and place the colored plastic wrap on top of the foil. Fold the edges around the back and secure with cellophane tape. Hang in a sunny location.

Multicultural skylore activities

The three activities that follow were used in the Science Materials for Bilingual Classrooms workshops with great success. The storytelling aspects of these activities were very popular with middle and elementary school teachers. Story Boxes was adapted from a church school curriculum; Create-Your-Own Sun Symbols was developed by ART-IST participant and facilitator Thea Cañizo, Vail Middle School, Tucson, Arizona, after the ART-IST pilot workshop; and Stained Glass Sun Symbols was adapted from a holiday activity that several staff members had used in scouts or other youth groups. We are continually searching for worldwide skylore and culture to incorporate into our program. ■

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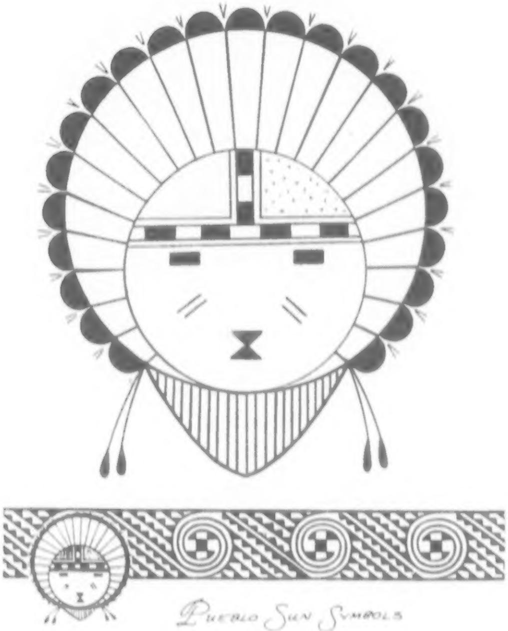
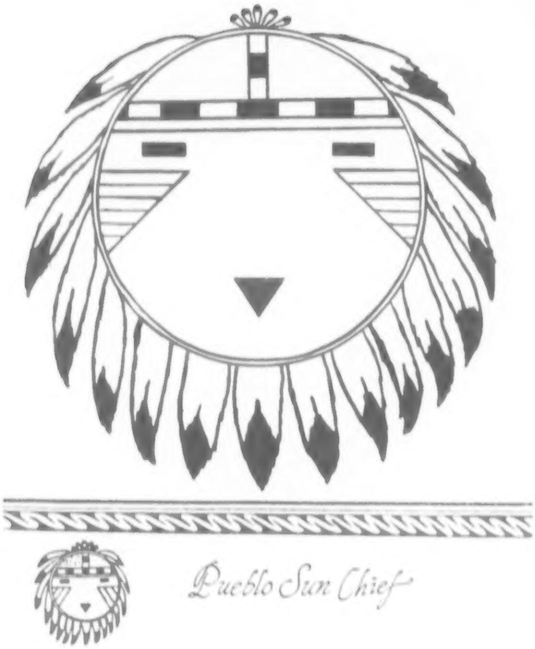
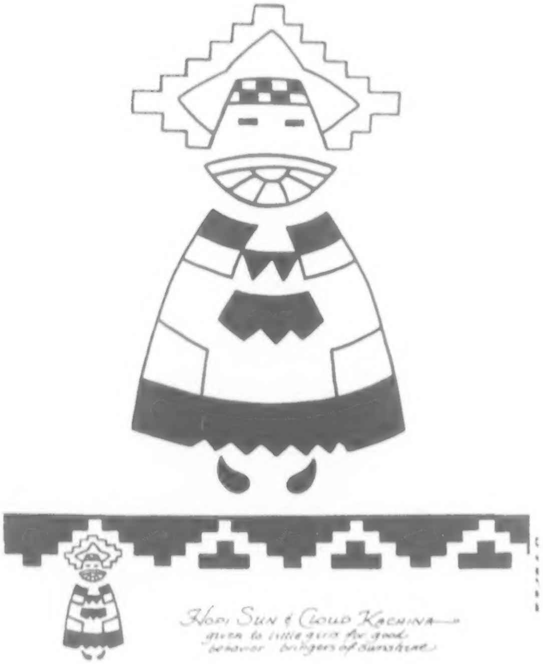


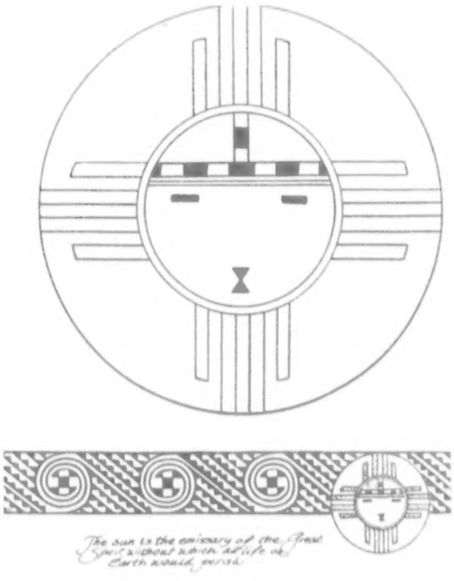
Pueblo Sun Symbols



Pueblo Sun Chief



Hopi Sun & Cloud Kachina—
given to little girls for good
behavior bringers of sunshine



The sun is the emissary of the Great
Spirit without which all life on
Earth would perish.

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Story boxes

Objectives

- To allow students to retell a myth or legend for themselves or to peers.
- To provide practice in storytelling, sequencing, and listening comprehension.

Advance preparation

- Box or other appropriate storage container
- Pictures of main characters, or patterns for tracing
- Large piece of fabric
- Scraps of cloth and felt
- Tagboard
- Scissors
- Glue
- Plastic or wooden figures

1. Choose an astronomical myth, legend, or folktale to share with the class, such as "The Moon Rope" or "How Coyote Arranged the Night Sky." (See Skylore Resources)
2. Make felt cut-outs, pictures glued to tagboard, figures, and other items to represent key figures and objects in the story.
3. Select a piece of fabric of an appropriate color and type to serve as a surface to play out the story. The size of the fabric will depend on the size and number of the characters, but a 30x30cm piece often works well.
4. Wrap the characters and other small objects in the background fabric and place them in the box or basket. Label with the name of the story (or with representative pictures if students are not yet reading).

Teacher procedure

1. Tell the class the myth, legend, or folktale you chose. Discuss the origin of the story, including the time and culture.
2. Discuss the general differences between science and lore.
3. Allow students, either individually or in small groups, to take turns using the story box to retell the story. Emphasize to students that the stories were very important to their originators, and thus the story boxes should be treated gently. All pieces must be wrapped in the background cloth and stored carefully in the box after use.
4. Allow students to choose other options for responding to the story as well, such as drawing, painting, using clay, or writing their own legend.

Some of the techniques used in the previous activity were adapted from Young Children and Worship by S.M. Stewart and J.W. Berryman (Westminster/John Knox, Louisville, KY, 1989).

Skylore resources

Barlow, G., and Stivers, W. (1980). *Leyendas Mexicanas*. Skokie, IL: National Textbook Company. (Mexican legends in easy-level Spanish.)

Ehlert, L. (1992). *The Moon Rope (Un Lazo a la Luna)*. New York: Harcourt Brace Jovanovich. (Peruvian folktale about the fox in the Moon.)

Gerson, M.J. (1992). *Why the Sky is Far Away*. Boston: Little Brown and Company. (A Nigerian folktale.)

Hadley, E., and Hadley, T. (1989). *Legends on the Sun and Moon*. Cambridge, England: Cambridge University Press. (Tales from India, Polynesia, Armenia, Nigeria, and other countries.)

Jablow, A., and Withers, C. (1969). *The Man in the Moon: Sky Tales from Many Lands*. New York: Holt, Rinehart and Winston. (Stories from around the world.)

Krupp, E.C. (1989). *The Big Dipper and You*. New York: Morrow Junior Books. (Science, history, and mythology relating to the Big Dipper.)

Mayo, G.W. (1990). *North American Indian Stories, Star Tales*. New York: Walker and Company. (Includes tales about the Milky Way, Orion, and the Big Dipper.)

Mollel, T.M., and Morin, P. (1990). *The Orphan Boy*. New York: Clarion Books. (Maasai tale about the planet Venus.)

Monroe, J.G., and Williamson, R.A. (1987). *They Dance in the Sky, Native American Star Myths*. Boston: Houghton Mifflin. (Contains "How Coyote Arranged the Night Sky.")

Riordan, J. (1985). *The Woman in the Moon and Other Tales of Forgotten Heroines*. New York: Dial Books for Young Readers. (Title story is from the Chippewa.)

Staal, J. (1988). *The New Patterns in the Sky*. Blacksburg, VA: McDonald and Woodward. (Illustrations and stories that give multicultural perspectives on constellations and star patterns.)

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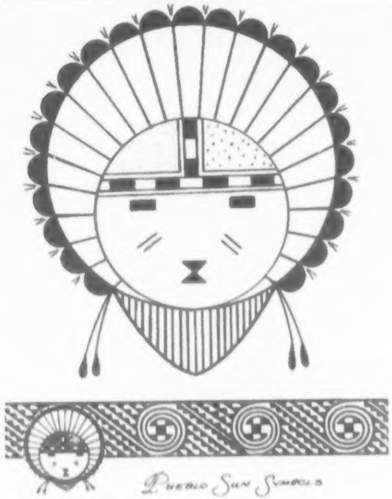


From Indian Designs by David & Jean Villasenor

RESOURCES FOR EXPLORING SKYLORE

(THE ASTRONOMICAL MYTHOLOGY OF MANY CULTURES)

by Scott Hildreth and Andrew Fraknoi
Astronomical Society of the Pacific

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

Compilations and Overviews of Astronomical Stories:

Krupp, E. *Beyond the Blue Horizon.* 1991, Harper Collins. The best modern reference on the astronomical myths and folktales of many cultures.

Aveni, A. *Conversing with the Planets.* 1992, Times Books. A leading astronomical anthropologist explains and celebrates the myths of many cultures in their own contexts.

Cuff, C., et al. *Astronomy of the Americas.* 1993, Lawrence Hall of Science, University of California, Berkeley, CA 94720. Volume 11 of the Planetarium Activities for Student Success Series; highlights astronomical perspective of five Native American cultures. (Volume 12 of the same series is on Stonehenge.)

Jablow, A. & Withers, C. *The Man in the Moon: Sky Tales from Many Lands.* 1969, Holt, Rinehart, & Winston.

Laurie, A. *The Heavenly Zoo: Legends and Tales of the Stars.* 1979, Farrar.

Lum, P. *The Stars in our Heavens: Myths and Fables.* 1948, Pantheon Books.

Motz, L. & Nathanson, C. *The Constellations: An Enthusiast's Guide.* 1988, Doubleday. Gives the legends and astronomical information for each of the 88 constellations.

Ridpath, I. *Star Tales.* 1988, Universe Books. Very nice guide to the Greek and Roman legends associated with the bright stars and constellations.

Staal, J. *The New Patterns in the Sky: Myths and Legends of the Stars.* 1988, McDonald & Woodward. Myths from many cultures organized by constellation.

Williamson, R. *Living the Sky: The Cosmos of the American Indian.* 1984, Houghton Mifflin. An expert describes the astronomical thinking of Native Americans.

Gingerich, O. "The Origin of the Zodiac" in *Sky & Telescope*, Mar. 1984, p. 218.

Carlson, E. "America's Ancient Skywatchers" in *National Geographic*, Mar. 1990.

Farrington, O. "The Worship and Folk-lore of Meteorites" in *Journal of American Folklore*, 1900, vol. 13, p. 199.

Canizo, T. "Legends and Myths of the Sky" in *Science Scope*, Mar. 1994, p. 31. A teacher tells how she uses sky lore in the classroom.

Books of Myths which Include Some Astronomy

Bruchac, J. *Return of the Sun: Native American Tales from the Northeast Woodlands.* 1989, Crossing Press.

Caduto, M. & Bruchac, J. *Keepers of the Earth: Native American Stories and Environmental Activities for Children.* 1989, Fulcrum Press. Combines legends with science activities.

Dayrell, E. *Why the Sun and the Moon Live in the Sky.* 1977, Houghton Mifflin.

Edmonds, M. & Clark, E. *Voices of the Winds: Native American Legends.* 1989, Facts on File.

Erdoes, R. & Ortiz, A. *American Indian Myths and Legends.* 1984, Pantheon.

Hulpach, V. *American Indian Tales and Legends.* 1965, Golden Pleasure Book.

SELECTED READINGS FOR STUDENTS

Grades 4-6

Asimov, I. *Mythology and the Universe.* 1990, Gareth Stevens. Myths and stories from a number of cultures.

Birdseye, T. *A Song of Stars.* 1990, Holiday House. An Asian legend involving the stars Vega and Altair.

Ehlert, L. *Moon Rope (Un Lazo a la Luna).* 1992, Harcourt Brace Jovanovich. A Peruvian folktale told in both English and Spanish.

Gerson, M. *Why the Sky is Far Away: A Nigerian Folktale.* 1992, Little and Brown.

Hadley, E. & T. *Legends of the Sun and the Moon.* 1983, Cambridge U. Press. Features myths from a number of cultures.

Krupp, E. *The Big Dipper and You.* 1989, Morrow Junior Books. Really for younger children, but has stories about the Big Dipper from a number of cultures.

Lee, J. *Legend of the Milky Way.* 1982, Reading Rainbow. A Chinese folktale.

Mayo, G. *Star Tales: North American Indian Stories* and *North American Indian Stories: More Star Tales.* 1987, 1990, Walker. Two collections of native American constellation stories.

Riordan, J. *The Woman in the Moon and Other Tales of Forgotten Heroines.* 1985, Dial Books.

Vautier, G. *The Shining Stars* and *The Way of the Stars.* 1989, Cambridge U. Press. Retelling of the Greek star legends with star maps.

Howard, S. "Legends of the Shona Sky" in *Odyssey,* 1991, issue 6, p. 2. Longer article on the astronomical myths of a tribe in Zimbabwe.

Marston, E. Circles and Serpents: How Native Americans Watched the Skies" in *Odyssey,* 1990, issue 9, p. 4.

Odyssey magazine has had an ongoing series of short articles on the mythology of planets, stars, and constellations, including myths from many cultures.

Grades 7-9

Budd, L. *Full Moons: Indian Legends of the Seasons.* 1971, Rand McNally.

Jobes, G. & J. *Outer Space: Myths, Name Meanings, and Calendars.* 1964, Scarecrow Press.

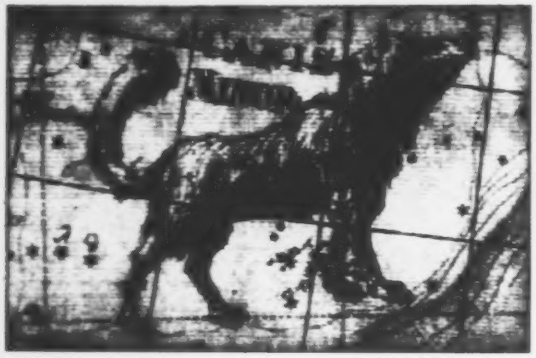
Monroe, J. & Williamson, R. *They Dance the Sky: Native American Star Myths.* 1987, Houghton Mifflin. Superb collection from many regions.

Weiss, M. *Skywatchers of Ages Past.* 1982, Houghton Mifflin. Introduction to archaeoastronomy.

SELECTED AUDIOVISUAL MATERIALS

The Feather Moon: American Indian Star Tales, Tales of the Sun and the Moon, and *The Star Husband.* (1990, 1992, 1994 audio tapes, from the Astronomical Society of the Pacific.) Three cassettes of native American legends, related by story-teller Lynn Moroney.

We would like to acknowledge assistance in compiling this list from Nancy Lebofsky and the staff of Project ARTIST at the University of Arizona, Cary Sneider and others at the Lawrence Hall of Science, University of California, and Ed Krupp at the Griffith Observatory.



RESOURCES FOR EXPLORING THE NAMING OF ASTRONOMICAL OBJECTS

by Andrew Fraknoi
Foothill College &
the Astronomical Society of the Pacific

NAMING OBJECTS AND FEATURES IN THE SOLAR SYSTEM

At first, the naming of moons and features (mountains, craters, "continents") on other worlds was a haphazard affair, often left to the discoverer or the person who published the most attractive maps. Gradually, astronomers brought some order into our system of planetary nomenclature, eventually handing responsibility for new names to a special working group of the International Astronomical Union. The long history of celestial names is full of good anecdotes and political battles. Today, as our close-up surveys reveal more and more features that "demand" to be named, the task is to come up with fair rules and an international system of suggesting appropriate names. See:

Kross, J. "What's in a Name?" in *Sky & Telescope*, May 1995, p. 28. Very good summary.

Masursky, H. & Strobell, M. "Memorials on the Moon" in *Sky & Telescope*, Mar. 1989, p. 265. Naming craters after astronauts and cosmonauts.

Menzel, D., et al. "Report on Lunar Nomenclature" in *Space Science Reviews* vol. 12, no. 2, p. 136 (1971).

Millman, P. "Names on Other Worlds" in *Sky & Telescope*. Jan. 1984, p. 23.

Moore, P. "The Naming of Pluto" in *Sky & Telescope*, Nov. 1984, p. 400.

Sagan, C. "A Planet Named George" in *Broca's Brain*. 1979, Random House. Very well-written introductory essay on how celestial objects are named.

Stewart, J. *Moons of the Solar System*. 1991, McFarland. Encyclopedic reference with much information on the derivation of names.

Strobell, M & Masursky, H. "Planetary Nomenclature" in *Planetary Mapping*, edited by R. Greeley & R. Batson (1990, Cambridge U. Press.) The definitive guide to how worlds and features are named; partly technical.

Westfall, J. "The Luna Incognita Project" in *Sky & Telescope*, Nov. 1991, p. 556.

NAMING STARS AND NEBULAE

Despite the advertisements you can sometimes hear on the radio at holiday times for a way to name a star after a person of your choice, stars are not named after people. In fact, most stars, nebulae, and galaxies do not have names: they are known by their locations in the sky or by a catalog numbers. The few names we do use come from an older tradition.

Allen, R. *Star Names: Their Lore and Meaning*. 1899, 1963, Dover Books. Classic, dense book on the derivations of star names.

Gingerich, O. "The Origin of the Zodiac" in *Sky & Telescope*, Mar. 1984, p. 218.

Kunitzsch, P. "How We Got Our Arabic Star Names" in *Sky & Telescope*, Jan. 1983, p. 20.

MacRobert, A. "Names of the Stars" in *Sky & Telescope*, Sep. 1992, p. 278.

Skiff, B. "M is for Messier: A Brief History of Astronomical Catalogs" in *Sky & Telescope*, Apr. 1993, p. 38. How nebulae are designated.

M

ACROSS THE CURRICULUM

674

ACTIVITIES INCLUDED IN ACROSS THE CURRICULUM

ACTIVITY	ESTIMATED GRADE LEVEL											
Grades	1	2	3	4	5	6	7	8	9	10	11	12
M-1. Who Was Right? Students learn how Columbus based his expedition on an incorrect assumption for the size of the Earth.			■	■	■	■	■	■	■	□	□	□
M-2. The 12 Tourist Wonders of the Solar System Students create a list of interesting places in the solar system and write a travel brochure for an imaginary visit.			■	■	■	■	■	■	■	■	■	■
M-3. Astronomy in the Marketplace Students create a list of consumer products named after astronomical objects.			■	■	■	■	■	■	■	■	■	■
M-4. Finding the Music of the Spheres: Astronomy in Music Students create lists of songs and other pieces of music which relate in some way to astronomy.							■	■	■	□	□	□
M-5. Women in Astronomy: Some Activities to Get Students Thinking Students investigate the contributions and lives of women astronomers to better understand the challenges and difficulties faced by women in science.							□	□	□	■	■	■
M-6. Picturing an Astronomer Students draw their image of an astronomer and discuss their assumptions.							□	□	□	■	■	■
M-7. Puzzling Space Collection Students search for astronomy terms in a word-search or "lettergram" puzzle.						□	■	■	■	□	□	□

675

■ - Grade levels recommended by authors □ - Can be extended to these grade levels

ABOUT THE ACTIVITIES: ACROSS THE CURRICULUM: INTERDISCIPLINARY TEACHING IDEAS

KEY IDEAS IN "ACROSS THE CURRICULUM: INTERDISCIPLINARY TEACHING IDEAS"

- Teaching "across the curriculum" means helping students to make connections among all of the various subjects they learn in school.
- Interdisciplinary teaching can be accomplished in several different ways. At the simplest level, teachers can coordinate their teaching. At a deeper level, teachers may offer a single course that cuts across two or more disciplines.
- The *Benchmarks for Science Literacy* solidly supports interdisciplinary teaching in several ways, including integrated planning, interconnected knowledge, and coherence (in which students' experiences add up to more than a collection of miscellaneous topics).
- Interdisciplinary efforts very strongly supported by the *Benchmarks* include the connections between science and history, science and mathematics, science and technology, and science and human society.

Teaching "across the curriculum" means helping students to make connections among all of the various subjects they learn in school, from science and social studies to art, music, and literature. The more connections that students are able to make, the easier it will be for them to see the relevance of new knowledge and to apply what they learn in school to everyday life.

Interdisciplinary teaching can be accomplished in several different ways. At the simplest level, teachers can coordinate their teaching so that students learn similar ideas in different courses at about the same time. For example, students might be learning about the scale of the solar system in science class while they read a science fiction story about the solar system in their English class. At a deeper level, teachers may offer a single course that cuts across two or more disciplines. For example, a unit on Columbus might cover both the historical story of his voyage and the impact that Spanish contact had on Native Americans, as well as how he used the stars to navigate and tell time on board ship.

The *Benchmarks for Science Literacy* solidly supports interdisciplinary teaching in several ways: "First, integrated planning—the curriculum in science, mathematics, and technology (and perhaps more) should be the result of the collaboration of teachers from all the relevant subjects and all grade levels, not a parceling out to grade and subject specialists. Second, interconnected knowledge—the students' experiences should be designed to help them see the relationships among science, mathematics, technology and between them and other human endeavors. Third, coherence—the students' experiences need to add up to more than a collection of miscellaneous topics, whether under themes (everything about, say, salmon) disciplinary subject headings (Principles of Chemistry), or activities ('neat things for kids to do')." (*Benchmarks*, page 320.)

An interdisciplinary effort that is very strongly supported by the *Benchmarks* is the connection between science and history. Two examples of units which are outlined in some detail in Chapter 10, Historical Perspective, are the Copernican Revolution (Displacing the Earth from the Center of the Universe) and the Newtonian Synthesis (Uniting the Heavens and the Earth). Other chapters are concerned with the connection between science and mathematics, technology, and human society.

The activities in this section offer ideas for relating astronomy to other areas of the curriculum. You are invited to use them as a springboard in developing your own interdisciplinary units that reflect your own interests and those of your students.

WHO WAS RIGHT?

ACTIVITY M-1

GRADE LEVEL: 3-9

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What's This Activity About?

History has left many students with the impression that it was Columbus who "proved" that the Earth was round, not flat. But astronomers knew many centuries earlier that our planet was indeed closely spherical. A more crucial question for Columbus was the circumference of our planet, and the distances between Spain and Asia via land and ocean. This activity is really a history lesson that incorporates science, comparing Columbus' estimate for the size of the Earth with estimates based on Eratosthenes' measurements.

What Will Students Do?

Students review Columbus' claim for the circumference of the Earth, and compare it with the view of scientists from his time. Students discuss who was right, why, and whether they as King or Queen would have agreed to the expedition.

Tips and Suggestions

- This activity raises the question about how scientists like Eratosthenes and Ptolemy measured the size of the Earth. Consider doing the activity "How Big is the Earth?" in the section *The Planets* first.
- Study the culture of Spain in Columbus' time, and compare the cost of his voyage to the costs of scientific exploration today.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
The size of the Earth	Comparing Evaluating	Scale

Who Was Right?

When Christopher Columbus proposed his plan to sail west across the great Ocean Sea, he believed there was only one ocean, and one great body of land. Columbus's plan was turned down several times before he succeeded in convincing the Spanish monarchy to support his venture. If he found a westward route to the Indies, Columbus knew that he would gain great wealth and fame for himself and for his sponsors, King Ferdinand and Queen Isabella. Why did it take Columbus so many years to obtain the ships and resources he needed? Why was he turned down so many times by monarchs all over Europe? It all has to do with three questions about geography. How big is the Earth? How wide is the ocean? How long does it take to sail across the Ocean Sea to the Indies?

Before the Lesson

Make one copy of each activity for every student, using masters on pages 43–45:

Who Was Right?—Part 1
Who Was Right?—Part 2
Who Was Right?—Part 3

In Class

Who Was right, Eratosthenes or Columbus?

1. Columbus did not have to prove that the Earth is shaped like a ball, but he did argue with the Queen's learned counselors. What was the argument about, and who was right?

2. Divide the class into teams of two or three students. Hand out the three activity sheets one at a time, allowing time for the students to read and discuss them in teams. Then lead a class discussion, answering questions as necessary.

3. As you will see when reading the student activity sheets, one argument was over the size of the Earth. The other is over how much of the Earth is covered by land. Columbus believed he could cross the Ocean Sea in one month. The counselors disagreed, arguing that it would take three months. Columbus's ships carried enough water and food for about one month, which meant that he and his crew could not make a three-month ocean crossing without restocking the ships. Although the counselors were right, Columbus was lucky. He made a trip of about one month and accidently arrived on islands that he believed were off the coast of the Indies. Columbus never gave up his belief that the world was small. Even though he made four voyages of exploration to Caribbean islands and traveled along the coast of the Central American mainland, he always believed he had discovered a new route to the Indies.

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Who Was Right?— Eratosthenes or Columbus? — Part 1

Queen Isabella and King Ferdinand of Spain appointed a committee to consider Columbus's plan to reach the Indies by sailing west. The committee met in several places over the years. Columbus traveled to the meeting sites so he would be available to answer their questions.

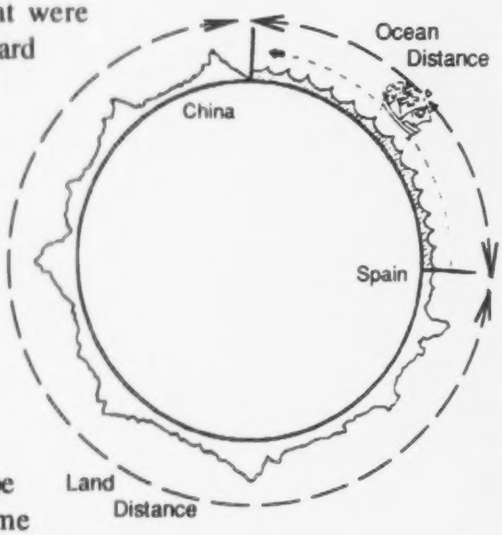
Salamanca in December of 1486 was only one of these meeting places. It is probably the most famous because it was an important center of learning in Spain. The University of Salamanca was one of four great European universities of the time, together with the universities at Paris (France), Bologna (Italy), and Oxford (England).

Most educated people in fifteenth-century Europe believed that the Earth was shaped like a ball. The Queen's counselors, who were professors in Salamanca, agreed with Columbus on this point. Their biggest concern was with Columbus's claim that the distance from Spain to China, sailing west across the Ocean Sea, was so short. He had to convince them that the voyage was practical and within the possibilities of normal ships.

How did Columbus figure out the distance to China?

First, Columbus figured out the distances that were already known. People had already traveled eastward by land from from Europe to China and estimated the distance they had traveled. Second, Eratosthenes and others had measured the distance around the Earth.

So, if Columbus subtracted the distance across the land from the distance around the Earth, he would know the distance from Spain to China, westward over the ocean. Remember, Europeans did not know that the Americas would be in the way.



Everyone who argued about how long it would be across the Ocean Sea to China used the same formula. The ocean distance *equals* the Earth's circumference *minus* the land distance.

630

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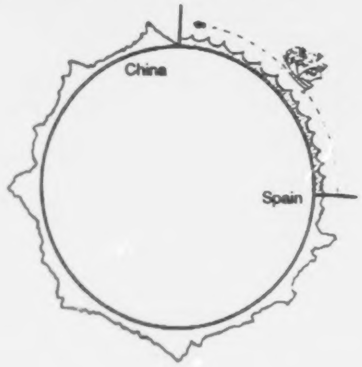
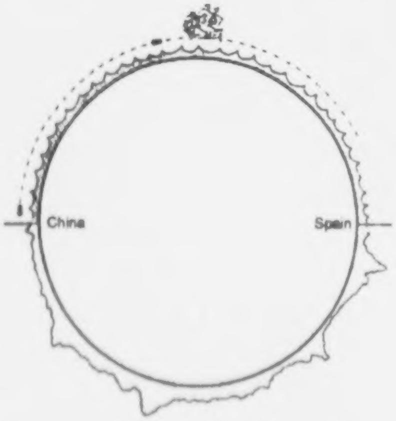
Who Was Right?— Eratosthenes or Columbus? — Part 2
Three Views of the Earth



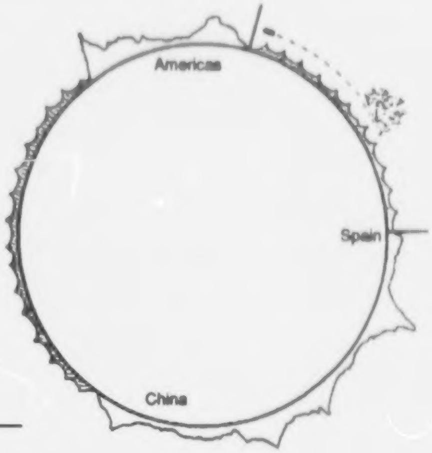
Columbus claimed that the Earth is only 18,800 miles in circumference, and the land route from Spain to China is about 15,000 miles. How far did he think it would be to sail westward from Spain across the Ocean Sea to the Indies?

__________________miles



The professors at Salamanca disagreed. They thought the distance around the Earth was at least 20,000 miles as measured by Ptolemy (A.D. 150), and that the land route from Spain to China was no more than about 10,000 miles. How far did the professors at Salamanca think it would be to sail westward to the Indies?

__________________ miles



The modern view is that the distance around the Earth is about 24,900 miles, and the land route from Spain to the Indies is about 8,000 miles. How far would Columbus have had to sail to reach the Indies?

__________________miles

Why did Columbus *think* he reached the Indies, even though he made landfall in the Americas?

____

____

____

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Who Was Right?— Eratosthenes or Columbus? — Part 3

Imagine that you are transported back in time to the university at Salamanca. You have an opportunity to listen to the historic argument between Columbus and the professors, appointed by King Ferdinand and Queen Isabella to give their expert opinions.

Columbus's presentation. Columbus says that it will take about one month to cross the great Ocean Sea and arrive in China. Ships of that time could carry enough fresh water and food for about a month, so there will be no problem in getting to China.

1. How big did Columbus believe the world to be? ____________________

2. How much of the world did Columbus believe was covered with land?

____

3. If you were one of the professors, what would you like to ask Columbus?

____

____

The professors respond. The professors of Salamanca based their opinions about the world on astronomers like Eratosthenes and Ptolemy.

4. How big did the professors believe the world to be?____________________

5. How much of the Earth did they think was covered by land? ______________

6. What do you think the professors would have said to Columbus?____________

____

The modern view. Look at the modern view of the world.

7. Who was closer to the truth, Columbus or the professors?________________

8. If you were the King and Queen of Spain, would you have provided Columbus with three ships and a crew to try out his plan? ____________________

Why or why not? ____________________________________

____

____

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THE TWELVE TOURIST WONDERS OF THE SOLAR SYSTEM

ACTIVITY M-2

GRADE LEVEL: 3-12

Source: This activity was written by Andrew Fraknoi, Astronomical Society of the Pacific, 390 Ashton Ave., San Francisco, CA 94112, (415)337-1100. Copyright © 1995 by Andrew Fraknoi.

What's This Activity About?

This activity makes an assessment of students' understanding of different planetary features. It asks students to describe the most fascinating places they have encountered as they studied the planets, and to create a travel brochure describing these places. This activity is especially useful for students who expect science to be all numbers, math, and facts. Here, the writers and artists can emerge, and their imaginations can be exercised. Asking students to create a travel brochure also teaches about writing for a particular audience and purpose. If you teach about the solar system, consider this activity!

What Will Students Do?

Students create and justify their own list of the most interesting place in the solar system. Students can write their list in the form of a travel brochure or as some other creative writing exercise.

Tips and Suggestions

- Combine this activity with "Invent an Alien" described in the *Space Exploration and SETI* section, or with a tour of a scale model of the solar system.
- Have students design and illustrate their travel brochures on posters and display them for others to see.

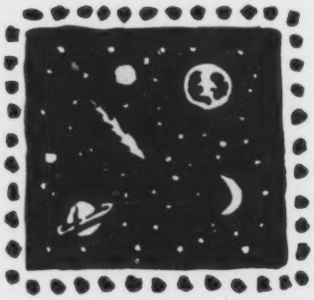
What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Features of the planets	Imagining	Structure
Moons and objects in the solar system	Communicating	Diversity and Unity

The 12 Tourist Wonders of the Solar System

by Andrew Fraknoi

The Astronomical Society of the Pacific



Aims:

This activity is designed to:

1) help students to synthesize and communicate what they have learned about the solar system

2) encourage them to do further library research

3) develop writing and art skills and connect those with science

The Activity

After a class has studied the planets and satellites that make up our solar system, the students are asked to select the most impressive sights on the worlds they have studied. Have the students work in groups (as travel agencies of the future) or as individuals to pick their favorite places in the solar system. It is best to introduce the project before you start a unit on the planets so that students can look for especially interesting features on each world while they are learning about it.

Their task is to come up with an impressive travel brochure for a tourist (with unlimited resources) who wants to see the 12 greatest wonders of the solar system. Assume that the tour will provide all the equipment needed to help participants survive on each world. Have each group separately select their 12 sights, and then let groups compare their choices. (For younger students, five or six sites may be enough.) As an alternative, have each group select one planet or celestial object and create an in-depth travel brochure or poster about this planet.

The travel brochures might discuss the following details to help the celestial tourist plan for the trip:

1) How long will it take to get there?
2) What will the weather be like at the site?
3) What equipment and "clothing" would be needed to explore each site?
4) What sporting events (climbing, jumping, tobogganing, etc.) could be held at each site?
5) What would it take to provide overnight accommodations at each site?
6) In case local authorities decide to close the site during the busy tourist season, are there similar sites elsewhere in the solar system that could be substituted in the tour?

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When the Brochures are Finished

- Have each group give an oral report, explaining their choices.
- Tally which sights each group selected and display the names and images of the highest rated sights on a bulletin board.
- Turn the brochures into travel posters to show families and display at school.
- Combine this activity with a "Create an Alien" activity where students design an alien whose characteristics would allow it to survive on a specific world.
- Use the brochures to provide tours of a scale model of the solar system.
- If a parent at the school is a travel professional, invite them to be a judge of the best brochure and give an astronomical prize.

To get the discussion started, here is our list of twelve favorites, with a few notes justifying the choices (but it's important to let the students do the choosing):

1. Olympus Mons, the largest volcano on Mars —

- 300 miles across at base: would cover state of New York
- 15 miles high (Mt. Everest: only 5.5 mi above sea level)
- caldera (crater at the top) is 40 miles across (could swallow most cities on Earth)

2. Valles Marineris, Mars' immense grand canyon

- an east-west canyon system, 2500 miles long
- at its deepest is 4.25 mi deep (average 2 mi deep)
- max width about 300 mi across

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3. Valhalla on Callisto (Jupiter's moon)

- concentric circle mountains that mark impact feature
- largest known "remains" of an impact in solar system
- rings extend 1800 mi in diameter
- central white region (icy) 370 mi across

4. Impact crater Herschel on Mimas (the "Death Star" moon)

- Mimas is Saturn's 8th satellite about 240 mi across
- crater Herschel is 81 mi across (1/3 diameter of world)
- central peak rises 20,000 ft high
- back side of the moon opposite Herschel is cracked
- impact any larger could have broken moon apart, creating another ring around Saturn

5. Great Cliff on Miranda

- Miranda is 11th moon of Uranus, about 300 mi across
- cliff over 6 miles high (Grand Canyon is roughly 1 mi)
- gravity is only 1.5% of Earth
- if you leap off, you have more than 5 minutes to regret it

6. Red Spot "Storm" on Jupiter

- 2 times size of Earth today (16,000 by 8500 mi)
- has been seen since invention of telescope; gets bigger and smaller
- rotating counterclockwise, it is a high-pressure system; takes about a week for 1 rotation

7. Dark Spot and "Scooter" on Neptune

- Neptune is 30,000 mi wide

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- Dark Spot: 6,000 mi wide (about size of Earth) probably a high pressure storm system like Jupiter's red spot; winds around it blow at 1300 mph
- takes 18.3 hours to orbit planet

8. The Rings of Saturn

- rings from tip to tip=171,000 miles (would fill up most of space between Earth and Moon)
- generally just 100 yards thick
- billions of particles from dust to mountain-sized, mostly water ice, but other ices and surface contamination likely
- tens of thousands of ringlets and divisions

9. The Maxwell Mountains of Venus

- highest mountains on Venus, rise 6 mi above the plains
- the base covers an area the size of Colorado
- only feature on Venus named after a man (James Clerk Maxwell, the Scottish physicist)
- on its side has a 60-mile wide impact crater named Cleopatra

10. Pele Volcano on Io

- the largest volcano on the most volcanic world we know
- the whole moon is "turning itself inside out"
- Pele's hoofprint shaped mound is enormous (in Voyager 1 photos, it was about the size of Alaska, but by the time Voyager 2 arrived, it had grown and changed its shape)
- its plume of expelled material was about 180 miles high
- the volcanoes like Pele on Io spew out sulfur and sulfur compounds

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11. The Caloris Basin on Mercury

- largest visible structure on its planet, 800 miles wide
- impact basin, partially "flooded" with lava long ago
- the sun shines directly into this basin when Mercury's orbit brings the planet closest to the Sun. This means Caloris has the highest noontime temperature on Mercury
- thus it's the hottest place in the solar system; bring something cool to drink if you plan a picnic

12. The Footprints of the Apollo 11 Astronauts on the Moon

- July 20, 1969, Neil Armstrong made the first human footprints on the Moon
- because the Moon has no atmosphere, there is no weather or liquid water
- the footprints will be preserved in the lunar soil for millions of years

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ASTRONOMY IN THE MARKETPLACE

ACTIVITY M-3

GRADE LEVEL: 3-12

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What's This Activity About?

Astronomy actually plays a much larger role in our lives than many people think. We use words like month (moonth) or disaster (literally "dis-aster," or "against the stars"), or refer to the days of the week (which are named after the Sun, Moon, and the five easily visible planets), without consciously making the connection to the Moon, the stars, or the planets. Astronomical terms are also used around the world in advertising, probably in part because of their universal identification and mysterious, exotic, or exciting connotations.

This activity helps to stimulate student's awareness of their world. As students brainstorm in groups, or search the aisles of a local supermarket for additional astronomical terms, they are becoming more familiar with astronomy, and with marketing!

What Will Students Do?

Students help to create a list of products that have been named after astronomical objects, which the class discusses. As a homework project, students search local stores or media for additional astronomical references.

Tips and Suggestions

- Use this activity as a group icebreaker, where each member introduces themselves, and each group tries to create their own list.
- Consumer products named after astronomical objects are just one avenue to explore. Students could also look for references to astronomy in favorite songs, movies, or poetry.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Influence of astronomy in everyday life	Observing Recording Communicating	Diversity and Unity

ASTRONOMY IN THE MARKETPLACE

The allure of astronomy is so strong that many companies have named products after astronomical objects. This activity allows students to compile a list of product names and develop new products using astronomical titles.

CONCEPT

Astronomy has influence outside the field of science.

OBJECTIVES

Students will:

- increase their familiarity with astronomical terms.
- observe astronomical terms in unexpected places.
- infer why names are chosen for consumer products.
- use creative thinking skills to develop an advertising campaign.

MATERIALS

large sheets of paper

PROCEDURE

Advanced Preparation:
This activity is best done over an extended period of time, but need not involve substantial amounts of class time.

1. Begin a discussion of the fascination of astronomy, asking students to list some common consumer products that have been named after astronomical objects. Here are some examples:

   Automobiles: Ford Taurus, Mercury Comet, Dodge Aries, Ford Galaxie, Nissan Pulsar, Toyota Corona, Chevy Nova, and Subaru. (Subaru is the Japanese name the Pleiades star cluster. The Subaru logo at the front of the car actually shows stars in the Pleiades star cluster.)

   Other Products: Comet cleanser, Milky Way and Mars candy bars, Pulsar watches, Quasar televisions, and Galaxy carpets (with a spiral galaxy as a logo).

2. After generating a short list, ask the students to spend the next few days looking around their homes, in local stores, and in magazines and newspapers for as many products and business names they can find related to astronomy. Have them bring in any items they can and put them on display in the classroom.

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3. Create a class list of the product names. Challenge the groups to produce the longest list.

4. Discuss why astronomical names have an appeal for businesses. What quality of a product is emphasized by use of astronomical names or images?

5. Extend this activity and integrate it with language and visual arts by asking students to devise their own astronomically-named product. Students can write and illustrate advertisements for their products. Have the students produce packages or samples of their new products, using common household materials. Ask them to write a paragraph extolling the virtues of their products, with emphasis on astronomical terms and images. Share their products and creative advertising campaigns in a class presentation.

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FINDING THE MUSIC OF THE SPHERES: ASTRONOMY IN MUSIC

ACTIVITY M-4

GRADE LEVEL: 7-9

Source: This activity was written by Andrew Fraknoi, Astronomical Society of the Pacific, 390 Ashton Ave., San Francisco, CA 94112, (415)337-1100. Copyright ©1995 by Andrew Fraknoi.

What's This Activity About?

Similar to "Astronomy in the Marketplace," this activity encourage students to become even more aware of astronomy's universal appeal, and to connect what they learn about astronomy to their interests in music.

What Will Students Do?

Students work in teams to brainstorm a list of songs whose titles involve astronomy. For later grades, students can list music relating to a specific aspect of astronomy, or songs that teach the listener something about astronomy.

Tips and Suggestions

- In addition to using song titles, students can brainstorm any piece of music with astronomical terms in its lyrics, or with astronomical themes. You might also consider a similar activity looking for astronomical references in literature.
- Use this activity as an icebreaker. For fun, have each group sing part of their favorite song for the class.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Familiarity with astronomical terms	Observing Communicating	

Finding the Music of the Spheres: Astronomy in Music

by Andrew Fraknoi

The Astronomical Society of the Pacific

Aims:

1) *To spark students' interest in astronomy through music*
2) *To provide a fun, warm-up or follow-up activity for an astronomy unit*
3) *To show that composers have an interest in astronomy*
4) *To encourage students to do research outside the classroom*

Many students enjoy finding references to astronomy in pieces of music. From "Twinkle, Twinkle, Little Star" through the Beatles' "Here Comes the Sun" to Gustav Holst's Symphonic Suite "The Planets," astronomical objects or ideas are not difficult to find in all kinds of music. (See the attached list for some suggestions.)

The Activity

For Younger Students

Divide the class into teams and have them make a list of all the songs or pieces of music they have heard about whose titles involve astronomy. It's not necessary that the piece should have anything to do with astronomy, just that the name involve an astronomical concept (such as "You Are My Sunshine"). You might want to have students continue with the assignment at home, getting family members involved. Give an astronomical prize to each member of the team with the longest list, such as Milky Way or Starburst candy.

For Older Students

For students with a more sophisticated knowledge of music and astronomy, you could restrict the pieces that teams can list to those which actually have a real astronomical connection or teach the listener something about astronomy. This can lead to some interesting debates. For example, can you count Mozart's Jupiter symphony (a title that was not Mozart's and which refers to the Jupiter of mythology, not astronomy) or Holst's "The Planets" (based on the astrological characteristics associated with each planet)? And what about the Rolling Stones' "2000 Light Years From Home?" In this activity it is best to allow the teams at least a week, to give them time to consult their own and friends' collections of music recordings.

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Extension

When the team of scientists in charge of the Voyager mission to the planets realized that the two Voyager spacecraft would eventually leave the solar system and become (in a sense) our robot representatives to the Galaxy, they decided to put "a message in a bottle" on each spacecraft. The message contained information in the form of an audio and video record, with the sights and sounds of Earth, including many selections of music from around the world.

Ask each group of students to list suggestions they would have made if they had been asked to compile an audio recording with music representing our whole planet. (See the enclosed list of the music that was selected.) The full story of the record is given in Sagan, Carl, et al. Murmurs of Earth: The Voyager Interstellar Record (1978, Random House). After many years of wrangling among record companies, the Voyager record was finally released for Earth listeners in 1993, under the title Murmurs of Earth, and can be purchased from Warner News Media and through catalogs such as the one from the Planetary Society.

Voyager Record Music

(in sequence)

1. Bach, *Brandenburg Concerto No. 2* in F, First Movement, Munich Bach Orchestra, Karl Richter, conductor. 4:40.
2. Java, court gamelan, *Kinds of Flowers*, recorded by Robert Brown. 4:43.
3. Senegal, percussion, recorded by Charles Duvelle. 2:08.
4. Zaire, Pygmy girls' initiation song, recorded by Colin Turnbull. 0:56.
5. Australia, Aborigine songs, *Morning Star* and *Devil Bird*, recorded by Sandra LeBrun Holmes. 1:26.
6. Mexico, *El Cascabel*, performed by Lorenzo Barcelata and the Mariachi México. 3:14.
7. *Johnny B. Goode*, written and performed by Chuck Berry. 2:38.
8. New Guinea, men's house song, recorded by Robert MacLennan. 1:20.
9. Japan, shakuhachi, *Cranes in Their Nest*, performed by Coro Yamaguchi. 4:51.
10. Bach, *Gavotte en rondeaux* from the *Partita No. 3* in E major for Violin, performed by Arthur Grumiaux. 2:55.
11. Mozart, *The Magic Flute*, Queen of the Night aria, no. 14. Edda Moser, soprano. Bavarian State Opera, Munich, Wolfgang Sawallish, conductor. 2:55.
12. Georgian S.S.R., chorus, *Tchakrulo*, collected by Radio Moscow. 2:18.
13. Peru, panpipes and drum, collected by Casa de la Cultura, Lima. 0:52.
14. *Melancholy Blues*, performed by Louis Armstrong and his Hot Seven. 3:05.
15. Azerbaijan S.S.R., bagpipes, recorded by Radio Moscow. 2:30.
16. Stravinsky, *Rite of Spring*, Sacrificial Dance, Columbia Symphony Orchestra, Igor Stravinsky, conductor. 4:35.
17. Bach, *The Well-Tempered Clavier*, Book 2, Prelude and Fugue in C, No. 1. Glenn Gould, piano. 4:48.
18. Beethoven, *Fifth Symphony*, First Movement, the Philharmonia Orchestra, Otto Klemperer, conductor. 7:20.
19. Bulgaria, *Izlel je Delyo Hagdutin*, sung by Valya Balkanska. 4:59.
20. Navajo Indians, Night Chant, recorded by Willard Rhodes. 0:57.
21. Holborne, *Paueans, Galliards, Almains and Other Short Aeirs, The Fairie Round*, performed by David Munrow and the Early Music Consort of London. 1:17.
22. Solomon Islands, panpipes, collected by the Solomon Islands Broadcasting Service. 1:12.
23. Peru, wedding song, recorded by John Cohen. 0:38.
24. China, ch'in, *Flowing Streams*, performed by Kuan P'ing-hu. 7:37.
25. India, raga, *Jaat Kahan Ho*, sung by Surshri Kesar Bai Kerkar. 3:30.
26. *Dark Was the Night*, written and performed by Blind Willie Johnson. 3:15.
27. Beethoven, *String Quartet No. 13* in B flat, Opus 130, Cavatina, performed by the Budapest String Quartet. 6:37.

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Classical Music

[CD labels and numbers given in parentheses]

Bentzon, Niels: *Kronik (Feature) on Rene Descartes.* (BIS CD 79) First movement on "heavenly vortices."

Cage, John: *Atlas Eclipticalis for Flute and Other Instruments.* (Etcetera 3-KTC-3002)

Crumb, George: *Makrokosmos.* (Centaur CRC 2050, vol. I; 2080, vol. II) "Fantasy pieces after the Zodiac."

Dodge, Charles: *Earth's Magnetic Field.* (No CD; there was a record on the Nonesuch label). Electronic music based on the Sun's activity and its effect on our magnetic field.

Glass, Philip: *Einstein on the Beach.* (CBS M4K 38875) Opera meditates on Einstein's life, work, popular image.

Handel, George: "Total Eclipse" an aria from the opera *Sampson.* (Teldec 74871-2)

Hindemith, Paul: *The Harmony of the World Symphony.* (Chandos 9217) Drawn from opera based on Kepler's work.

Holst, Gustav: "Betelgeuse" from *Twelve Songs,* op. 48. (No CD yet; there was a recording on the Argo label.)

Holst, Gustav: *The Planets.* (many recordings) Suite based on the astrological and mythological aspects of planets.

Hovhannes, Alan: *Saturn.* (No CD yet; record on Poseidon label) Poem set to music.

Norholm, Ib: *Symphony #5: The Elements.* (Kontrapunkt 32005)

Smit, Leo & Hoyle, Fred: *Copernicus: Narrative & Credo.* (No CD; record on Desto label) Text by an astronomer.

Stockhausen, Karlheinz: *YLEM.* (No CD yet; record on Deutsche Grammophon) Players simulate oscillating universe.

Terenzi, Fiorella: *Music from the Galaxies.* (Island 422-848768-2) An Italian physicist sets electronic music to the pattern of radio emissions from a distant galaxy.

Van de Vate, Nancy: *Dark Nebulae, Distant Worlds.* (Vienna Modern Masters VMM 3008)

Widmer, Ernst: *Pulsars for Clarinet & Other Instruments.* (Grammont CTSP-32-2) A movement uses Doppler-effect.

[Music by an astronomer: Herschel, William: *Pieces for Organ interpreted by D. Proust.* (Disques DOM 1418: 4-6, rue du Donjon, 94300 Vincennes, France)

Popular Music

The Byrds: "CTA-102" on *Younger than Yesterday* (Columbia CK-09442) Song about a quasar and its radio signals.

Labelle: "Black Holes in the Sky" on *Phoenix* (No CD but a record was available on the Epic label)

Mannheim Steamroller: *Fresh Aire V* (American Grammophone AGCD-385) An album inspired by Johannes Kepler's 1609 book *Somnium,* about a trip to the Moon.

Pink Floyd: "Shine on You Crazy Diamond" on *Wish You Were Here* (Columbia CK-33453) About white dwarfs.

R.E.M.: "Kohoutek" on *Fables of the Reconstruction.* (IRS/MCA IRSD-5592) Comet Kohoutek came by in 1973.

Rush: "Cygnus X-1" on *Farewell to Kings* (Mercury 822546-2) Song about black holes.

Shorter, Wayne: *Super Nova* (Blue Note B21Y-84332) A jazz album.

Soundgarden: "Black Hole Sun" on *Superunknown* (A&M 314-540198)

Stewart, John: "An Account of Halley's Comet" on Sunstorm (Not CD, just record) He was member of Kingston Trio

They Might Be Giants: *Why Does the Sun Shine?* (Elektra short CD 66272-2) Adaptation of a 1959 educational song.

VanDeGraaf Generator: *H to He Who Am the Only One* (Blue Plate CAROL 1638-2) An album whose cover features the proton-proton chain of nuclear fusion in the Sun.

Vangelis: *Albedo 0.39* (RCA LPK1-5136) Includes such pieces as "Main Sequence" and "Sword of Orion"; no lyrics.

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For Further Reading

Fraknoi, A. "The Music of the Spheres: Astronomical Sources of Musical Inspiration" in *Mercury*, May/Jun 1977, p. 15; and "More Music of the Spheres" in *Mercury*, Nov/Dec 1979, p. 128.

Rodgers, J. & Ruff, W. "Kepler's Harmony of the World: A Realization for the Ear" in *American Scientist*, May/Jun 1979, p. 286.

Ronan, C. "Astronomy and Music" in *Sky & Telescope*, Sep 1975, p. 145.

Ronan, C. "William Herschel and His Music" in *Sky & Telescope*, Mar 1981, p. 195.

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WOMEN IN ASTRONOMY

Activity M-5

Grade Level: 7-9+

Source: This activity was written by Andrew Fraknoi, Astronomical Society of the Pacific, 390 Ashton Ave., San Francisco, CA 94112, (415)337-1100. Copyright ©1995 by the Astronomical Society of the Pacific.

What's This Activity About?

Like most sciences, astronomy has a history of discrimination towards women; it has gradually ebbed to the point where female astronomers today are frequently (but not always) considered "equal partners" with men. We can help our students understand that men and women are equals in science by consciously pointing out discoveries made by women, bringing in role models who are women, and encouraging girls to think about scientific careers.

What Will Students Do?

Students investigate the lives and work of women astronomers (past and present). Students share their findings with the class in oral or written reports. In the second part of the activity, students role play a discussion between a male and female astronomer about priorities in their lives.

Tips and Suggestions

- To put the activity in historical context, have students research what it was like for famous astronomers of the past, like Henrietta Leavitt or Annie Cannon. Encourage them to look at the society of that era, and how that society looked upon women in general.
- To complement this activity, show your class videos about women astronomers doing current research at major institutions around the world. One excellent source (for older students) is *The Astronomers*, produced by KCET in 1991 and distributed through PBS Video. Many of its six episodes include footage about female astronomers. Another video for high school students showing a female astronomy graduate student is Margaret Geller's *So Many Galaxies, So Little Time* about the attempt to map galaxies in the universe; it is available through the educational catalog of the Astronomical Society of the Pacific. The bibliography on women in astronomy in the last section of the notebook lists additional resources.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Women in science	Researching Communicating	

Women in Astronomy: Some Activities to Get Students Thinking

by Andrew Fraknoi
The Astronomical Society of the Pacific

Aims:

These activities are designed to help students

1) Learn about the contributions of women to astronomy

2) Develop library research skills

Remarkable as it sounds today, as late as 1950 women astronomers were still being denied the right to use the larger telescopes, such as the one on Mount Palomar in Southern California. Only recently have women astronomers become more equal partners with men in the enterprise of exploring the universe. To get a fuller sense of the history of women in astronomy, read the article, "Urania's Heritage" in the Resources section.

Life of a Woman Astronomer

1. Begin both activities by having students do the *Picturing an Astronomer* activity in this section. Discuss the drawings and students' assumptions about who might be an astronomer. What do students believe about what people become astronomers? Discuss why some students drew men, and others drew women. Do students know of any women astronomers? Have students list movies or TV shows they have seen with scientists in them How often are the scientists women in these shows?

2. Have groups of students research the life and work of a woman astronomer, either from history or working today. Ask them to think about and discuss what her daily life might have been like, and what difficulties she may have faced in getting her astronomical work done. You may need to help students by reviewing the role of women in general at the time the astronomer was doing her work. Then, have students present what they have learned to the class by giving a presentation, putting on a play, a recorded "radio interview," or creating a poster or mural. A bibliography of readings about individual women in astronomy is included in the *Resources and Bibliographies* section of the notebook.

3. This is a good opportunity to discuss how to find information in a library for students who have not done much library research. Get your school librarian involved. Encourage students to visit the local public library as well. Some of the articles and books on women astronomers may need to be obtained by using interlibrary loan or having the librarian search a computer database. More and more books for children on women scientists are appearing all the time, so don't limit students to the sources we list.

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Role Playing: Who Takes the Kids?

Two astronomers (Joe Comet and Jill Galaxy) meet while still graduate students and fall in love. They get married after they get their PhD degrees and, miraculously, manage to get jobs in the same city. Joe works at a university, where he does research and teaches students, and is nervous about getting tenure. Jill works at a research institute, funded by NASA, where she can continue her prize-winning research. Joe and Jill want to start a family, but are worried about the effect this will have on their careers. Divide students into small groups, and have each group discuss the potential problem and possible solutions. Who stays home with the kids when they are very young? Research astronomers must put in long hours to be top in their field. (They or you can feel free to make up more details about Joe and Jill's life, families, economic situation, etc.) Then each group should choose a boy to be Joe and a girl to be Jill (or vice versa) and discuss the situation with each other in front of the class based on what the group suggested.

More Ideas

- *Invite a woman astronomer to talk to your class. Contact a nearby university, NASA center, planetarium, or amateur astronomy club. Graduate students are often willing to visit classrooms.*
- *Order* Space for Women: Perspectives on Careers in Science, *a 20-page booklet published by the Harvard-Smithsonian Center for Astrophysics. Free copies of the booklet for students, teachers, and career advisors are available from the Harvard-Smithsonian Center for Astrophysics, Publications Department, MS-28, 60 Garden Street, Cambridge, MA 02138, (617)495-7461*
- *For more information about women and science, contact the Committee on the Status of Women in Astronomy at the American Astronomical Society, 2000 Florida Ave., NW Suite 400, Washington, DC 20009; the American Association of University Women, 1111 16th St. NW, Washington, DC 20036; or the Association for Women in Science, 1522 K St. NW, Washington, DC 20005, 1-800-886-AWIS.*

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PICTURING AN ASTRONOMER

ACTIVITY M-6

GRADE LEVEL: 4-9+

Source: This activity was written by Alan Friedman (New York Hall of Science) and Andrew Fraknoi (Astronomical Society of the Pacific, 390 Ashton Ave., San Francisco, CA 94112).

What's This Activity About?

Media and past experience have shaped and created our expectations of people in various careers, and astronomers are often "typecast" as middle-aged, white, "nerdy" males by students and adults alike. Yet astronomy is carried out around the world, by men and women in every country, by people young and old. This activity is a wonderful way to call attention to, and discuss, our preconceptions about who "can" be an astronomer.

What Will Students Do?

Students are told to picture an astronomer and describe or sketch a person who does astronomy. Students compare and discuss their different mental or artistic images.

Tips and Suggestions

- This is an excellent activity to start any unit on astronomy, at any grade level. The activity can be revisited at the end of a unit, to investigate whether students have begun to change their views.
- With videos, books, and activities that include women and minorities as equal contributors to the science of astronomy, we have a wonderful opportunity to dispel the myth that astronomy is the domain of a particular gender, age, or culture.

What Will Students Learn?

Concepts	Inquiry Skills	Big Ideas
Preconceptions about who does science	Recognizing Bias	

Picturing an Astronomer

An Activity by Alan Friedman,
New York Hall of Science
and ***Andrew Fraknoi***
Foothill College &
the Astronomical Society of the Pacific

Aims:

This activity is intended to

1) Help students look at their assumptions and stereotypes about who might be an astronomer

2) Encourage class discussion about scientists

The Activity

Before an astronomy unit or the first visit by an astronomer to your classroom, it can be instructive to have the students picture what an astronomer looks like and then discuss their assumptions. You might begin by reading the following paragraph:

> *Close your eyes and picture this scene. It is the end of a long night at the observatory and the astronomer is closing up as the first rays of dawn are seen on the horizon. The astronomer is tired and ready for a good day's sleep. Now focus in on the astronomer, coming toward you on the road that comes from the observatory. Get a good close look at the astronomer, rubbing tired eyes. Draw a picture (or for older students—get a clear mental image) of what the astronomer looks like.*

Note that this paragraph carefully omits any hint about the gender, age, or race of the astronomer. After students have made their own picture (as elaborately or as simply as time allows), have them compare and discuss the different pictures they came up with. In the past, there has been a tendency for participants of all ages to draw scientists as middle-aged white men. If your students also show such a tendency, this gives you an opportunity to discuss who became an astronomer in the past, and how the opportunities have expanded today and some (but by no means all) of the societal barriers have fallen.

Extensions:

1. Have students discuss the images of astronomers (or scientists in general) in the media. What gender, race, or age are astronomers they may have seen in the movies, on TV? Have any of them seen astronomers in the newspaper or on the TV news? What kind of news or stories about astronomy have the students read or seen recently? Is it good for our country that newspapers and TV feature a lot more information about sports stars and movie stars than the real stars?

2. Have students research what preparation is required to become an astronomer. An excellent booklet on "A Career in Astronomy" is available from the American Astronomical Society, 2000 Florida Ave., NW, #400, Washington, DC 20009.
3. Have students report on what it is like to do astronomy today. Reports can be orally or in writing, individually or as a team. Your students may be surprised by what they find. For example, much astronomy can be done during the day; many astronomers no longer work at the telescope in an open (and cold) dome, but rather sit comfortably in a heated control room at a computer console; and many astronomers never come near a telescope at all, concentrating instead on creating or refining astronomical theories. As an alternative, you can assign each group a different astronomer whose life and work they can research and report to the class about. A reading list on 20th century astronomers and their work is included in the *Resources & Bibliographies* section of this notebook.
4. Use this activity as preparation for a visit from a local astronomer to your classroom. Be sure the students do the activity before the astronomer comes. During the visit, the astronomer might begin by talking a bit about how he or she first became interested in astronomy. After the visit, give students an opportunity to talk about how the astronomer was similar or different from the mental picture they had before the visit.

PUZZLING SPACE COLLECTION

ACTIVITY M-7

GRADE LEVEL: 4-9+

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What's This Activity About?

There are many ways to encourage students to learn terms and become more familiar with the vocabulary of astronomy. This activity illustrates one kind of puzzle incorporating astronomical terms.

What Will Students Do?

Students search for astronomy terms in a word-search or "lettergram" puzzle.

Tips and Suggestions

This type of activity works well as homework, group work, or as an example so that students can devise their own puzzles for classmates.

What Will Students Learn?

Concepts
Astronomical terms

Inquiry Skills
Organizing
Communicating

Big Ideas

PUZZLING SPACE COLLECTION

This activity challenges students to find astronomical words hidden in a grid of letters. It provides the opportunity to build vocabulary while searching for less familiar space science words.

CONCEPT

A large vocabulary of usable astronomy words exists in our language.

OBJECTIVES

Students will:

- correctly find and spell astronomy-related words.
- contribute vocabulary findings to a group chart.
- practice using dictionaries and research books to find words and terms.

MATERIALS

Lettergram Puzzle
pencils
large sheets of paper for group word lists
dictionaries and astronomy books
markers

PROCEDURE

Advanced Preparation:
Make a copy of the Lettergram Puzzle for each student. You may wish to make a version of the sample puzzles to use on the chalkboard or overhead projector when explaining how to find letters in the Lettergram Puzzle. Obtain several large sheets of chart paper to create a group chart, as described in Step 6.

1. Distribute a copy of the Lettergram Puzzle to each student. Explain how to find words in the sample grid. It is important for students to understand how the words must be spelled using adjacent letters.

2. Allow students some class time to start finding as many words as possible. Encourage them to keep a list of words. These can be written on the back of the puzzle.

3. Provide access to dictionaries and astronomy books to encourage the search for unfamiliar space science words.

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4. Encourage students to use free time to continue searching for more words. Challenge them to reach a score of "astronaut." Remind them to check unclear spelling using a dictionary.

5. Plan a target date for students to share their discoveries and create a class list of the words found. How many different words can be revealed from this puzzle by your class? Can your group find more than 100 words?

6. On the appointed day, post several large sheets of paper for creating the class list. Divide the alphabet into several sections to allow several students to record words at the same time.

7. Have the students that found the fewest words put their words on the charts first. Use a round-robin system to continue adding words, with each student adding one or two words at a time. Remind students to double-check the list to be certain that only new and different words are being added each time. Checking off words on individual lists will help keep track of this information.

8. When all student lists have been completed, count the number of words found by the class. Encourage students to keep looking for words that can be added to the charts during their free time.

GOING FURTHER

The class word list can be used as a source of different language arts activities, including dictionary searches, word origin, alphabetizing, and story writing.

Classify the words found into various categories, such as astronomical bodies, inventions, and proper nouns.

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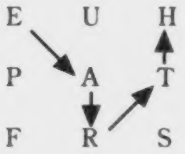
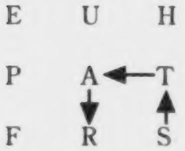
LETTERGRAM PUZZLE

Find the astronomy-related words hidden in the letters. Start with any letter and move to any adjacent letter. Letters may be used more than once, but each move must be to an adjacent letter.

Example:



EARTH



STAR

O	P	L	S	C	M	T	M
S	M	A	U	R	E	V	I
T	I	B	T	N	Y	T	Q
D	E	P	E	O	A	U	P
I	P	R	O	M	R	S	L
J	U	N	I	D	A	T	A

Score:

30 words - Astronaut
25 words - Space Scientist
20 words - Planetarium Director
15 words - Amateur Astronomer
10 words - Star Gazer

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GALILÆVS GALILÆI LYNCEVS PHILOSOPHVS ET MATHEMATICVS SER.mi HETRVRIÆ MAGNI DVCIS

RESOURCES FOR EXPLORING INTERDISCIPLINARY APPROACHES TO ASTRONOMY

by Andrew Fraknoi
Foothill College
12345 El Monte Rd.,
Los Altos Hills, CA 94022

This resource list is divided into two parts: first, books and articles that discuss relationships between astronomy and other fields, and then books or stories that are examples of such relationships. Neither listing is meant to be complete; rather, I hope the resources here can serve as a springboard for your own exploration.

1. READINGS RELATING ASTRONOMY AND OTHER FIELDS

ARCHAEOLOGY AND ASTRONOMY

Aveni, A. "Archaeoastronomy: Past, Present and Future" in *Sky & Telescope*, Nov. 1986, p. 456.

Canby, T. "The Anasazi: Riddles in the Ruins" in *National Geographic*, Nov. 1982, p. 554.

Cornell, J. *The First Stargazers*. 1981, Scribners. A science writer surveys the beginnings of astronomy, with emphasis on archaeoastronomy sites.

Gingerich, O. "The Basic Astronomy of Stonehenge" in *The Great Copernicus Chase*. 1992, Cambridge U. Press. Uses a wonderful Coca-Cola can model to explain how the builders thought of the sky.

Hadingham, E. *Early Man and the Cosmos*. 1984, Walker & Co. A clear first book on the subject of ancient sites.

Krupp, E. *Echoes of the Ancient Skies*. 1983, Harper & Row. An excellent introduction for the beginner on the thoughts and monuments of earlier cultures.

Krupp, E. "Springtime for Cadillacs" in *Sky & Telescope*, Mar. 1994, p. 64. About a row of half-buried Cadillacs in Texas that imitates the properties of some astro-archaeological monuments.

Williamson, R. *Living the Sky: The Cosmos of the American Indian*. 1984, Houghton Mifflin.

ART AND ASTRONOMY

Chaikin, A. "Images of Other Worlds" in *Sky & Telescope*, Nov. 1982, p. 423.

Davis, D. "The Worlds of Don Davis" in *Sky & Telescope*, June 1985, p. 503.

Gardner, M. "The Eerie Mathematical Art of Maurits Escher" in *Scientific American*, Apr. 1966, p. 110.

Hardy, D. *Visions of Space: Artists' Journey Through the Cosmos*. 1989, Limpsfield. Featuring the work of over 60 artists.

Hartmann, W., et al. *Cycles of Fire*. 1987, Workman. An introduction to stars and galaxies, with paintings by several astronomical artists, particularly Bill Hartmann who is both an artist and a planetary astronomer.

Hartmann, W., et al. *In the Stream of Stars: The Soviet/American Space Art Book*. 1991, Workman. Over 200 color paintings and text by artists in both countries.

Miller, R. *The Dream Machines*. 1993, Krieger. An illustrated history of the spaceship in art, science, and literature, by a noted space artist.

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Miller, R. & Hartmann, W. *The Grand Tour: A Traveler's Guide to the Solar System*, 2nd ed. 1993, Workman. A layperson's introduction to planetary astronomy, illustrated with many informed paintings of views not accessible to spacecraft cameras.

Miller, R. & Durant, F. *Worlds Beyond: The Art of Chesley Bonestell*. 1983, Donning. An album and tribute about the pioneering space artist.

Olson, D. & Doescher, R. "Van Gogh, Two Planets, and the Moon" in *Sky & Telescope*, Oct. 1988, p. 408.

O'Meara, S. "Kazuaki Iwasaki: Japan's Astronomer-Artist" in *Sky & Telescope*, July 1985, p. 64.

THE ENVIRONMENT AND ASTRONOMY

Crawford, D., ed. *Light Pollution, Radio Interference, and Space Debris*. 1991, Astronomical Society of the Pacific Conference Series Volume 17. A somewhat technical volume, but with a number of review papers that can be understood by most readers.

Hargrove, E., ed. *Beyond Spaceship Earth: Environmental Ethics and the Solar System*. 1886, Sierra Club Books. Essays on exploiting or preserving planets, space exploration, pollution in space, etc.

Waldrop, M. "The Long, Sad Saga of Mount Graham" in *Science*, 22 June 1990, vol. 248, p. 1479. The story of how a new site for telescopes in Arizona pits astronomers and environmentalists against each other. [See the sequel: Travis, J. "Scopes and Squirrels Return to Court" in Science, 2 Sep. 1994, vol. 265, p. 1356 .]

[see also under Light Pollution]

HISTORICAL EVENTS [HOW ASTRONOMICAL PHENOMENA INFLUENCED THEM]

Cowen, R. "The Tides of War: D-Day's Lunar Connection" in *Science News*, June 4, 1994, vol. 145, p. 360.

Olson, D. "Columbus and An Eclipse of the Moon" in *Sky & Telescope*, Oct. 1992, p. 437.

Olson, D., et al. "Columbus and the Sky of Jan. 17, 1493" in *Sky & Telescope*, Jan. 1991, p. 81. (Conjunctions in the sky)

Olson, D. "Pearl Harbor and the Waning Moon" in *Sky & Telescope*, Dec. 1991, p. 651.

Olson, D. & Doescher, R. "Lincoln and the Almanac Trial" in *Sky & Telescope*, Aug. 1990, p. 184.

Olson, D. & Doescher, R. "Paul Revere's Midnight Ride" in *Sky & Telescope*, Mar. 1990, p. 437.

Rubincam, D. & Rowlands, D. "The Night the Titanic Went Down" in *Sky & Telescope*, Oct. 1993, p. 79.

Schaefer, B. "Lunar Eclipses That Changed the World" in *Sky & Telescope*, Dec. 1992, p. 639.

Schaefer, B. "Solar Eclipses That Changed the World" in *Sky & Telescope*, May 1994, p. 36.

Vialle, J. & Hoff, D. "The Astronomy of Paul Revere's Ride" in *Astronomy*, Apr. 1992, p. 13.

LAW AND ASTRONOMY

Christol, C. "Space Law: Justice for the New Frontier" in *Sky & Telescope*, Nov 1984, p. 406.

Dickson, D. "Was Galileo Saved by a Plea Bargain" in *Science*, Aug. 8, 1986, p. 612.

Freitas, R. "Metalaw and Interstellar Relations" in *Mercury*, Mar/Apr 1977, p. 15.

Gingerich, O. "How Galileo Changed the Rules of Science" in *Sky & Telescope*, Mar. 1993, p. 32. On Galileo's trail and its resolution in the early 1990's.

Goodman, A. "The Diplomatic Implications of Extraterrestrial Intelligence" in *Mercury*, Mar/Apr. 1987, p. 56.

Hansen, J. "The Crime of Galileo" in *Science 81*, Mar 1981, p.14.

Hetherington, N. "Edwin Hubble: Legal Eagle" in *Nature*, 16 Jan 1986, vol. 319, p. 189.

Robinson, G. & White, M. *Envoys of Mankind: Principles for the Governance of Space Societies*. 1986, Smithsonian Inst. Press.

LIGHT POLLUTION

Crawford, D. & Hunter, T. "The Battle Against Light Pollution" in *Sky & Telescope*, July 1990, p. 23. A fine review of the current status of problems and solution.

Davidson, K. "Hype in Space: Billboards and Other Threats to the Dark" in *Mercury*, May/June 1993, p. 80.

Hendry, A. "Light Pollution: A Status Report" in *Sky & Telescope*, June 1984, p. 504.

Hunter, T. & Goff, B. "Shielding the Night Sky" in *Astronomy*, Sep. 1988, p. 47.

Mood, J. & S. "Palomar and the Politics of Light Pollution" in *Astronomy*, Nov. 1985, p. 6.

Pankonin, V. "Protecting Radio Windows for Astronomy" in *Sky & Telescope*, Apr. 1981, p. 308.

Sperling, N. "Light Pollution: A Challenge for Astronomers" in *Mercury*, Sep/Oct. 1986, p. 144.

Sullivan, W. "Our Endangered Night Skies" in *Sky & Telescope*, May 1984, p. 412. On how the pollution in light and radio waves can be detected from space.

LITERATURE AND ASTRONOMY

Friedman, A. "Contemporary American Physics Fiction" in *American Journal of Physics*, May 1979, p. 392. Good review article on a number of modern novelists who use physics ideas.

Friedman, A. & Donley, C. *Einstein As Myth and Muse*. 1985, Cambridge U. Press. Excellent exploration of the effect of Einstein and his work on the humanities and on popular culture.

Gingerich, O. "Great Conjunctions, Tycho, and Shakespeare" in *Sky & Telescope*, May 1981, p. 394.

Levy, D. "Astronomy in Some Works of Thomas Hardy" in *Sky & Telescope*, July 1990, p. 84.

Lovi, G. "Stargazing with Homer" in *Sky & Telescope*, Jan. 1989, p. 57. Brief introduction.

Nicolson, M. *Science and the Imagination*. 1956, Cornell U. Press. Essays on science and literature, with several on the telescope's influence.

Olson, D. & Jasinksi, L. "Chaucer and the Moon's Speed" in *Sky & Telescope*, Apr. 1989, p. 376.

Schaefer, B. "The Astronomical Sherlock Holmes" in *Mercury*, Jan/Feb. 1993, p. 9. Holmes' arch-enemy may have been based on Simon Newcomb, the famous 19th century astronomer.

MEDIA AND ASTRONOMY

Byrd, D. "Astronomy on the Air: The Stardate Radio Program" in *Mercury*, Jan/Feb. 1980, p. 7.

Goldman, S. "Prime-Time Astronomers: The Astronomers TV Series" in *Sky & Telescope*, May 1991, p. 472.

Goldsmith, D. "Two Years in Hollywood: An Astronomer in Television Land" in *Mercury*, Mar/Apr. 1991, 34. The chief writer for "The Astronomers" TV program tells the story of his work on the show.

O'Meara, S. "Jack Horkheimer: Star Hustler" in *Sky & Telescope*, May 1989, p. 544.

Pierce, D. "Project Universe: Astronomy on Public Television" in *Mercury*, Sep/Oct 1978, p. 118.

Robinson, L. "Hubble's Troubles: NASA and the Media" in *Sky & Telescope*, Oct. 1990, p. 340. An editorial.

MUSIC AND ASTRONOMY

Fraknoi, A. "The Music of the Spheres:

Astronomical Sources of Musical Inspiration" in *Mercury*, May/Jun 1977, p. 15.

Fraknoi, A. "More Music of the Spheres" in *Mercury*, Nov/Dec 1979, p. 128.

Rodgers, J. & Ruff, W. "Kepler's Harmony of the World: A Realization for the Ear" in *American Scientist*, May/Jun 1979, p. 286.

Ronan, C. "Astronomy and Music" in *Sky & Telescope*, Sep 1975, p. 145.

Ronan, C. "William Herschel and His Music" in *Sky & Telescope*, Mar 1981, p. 195.

Sagan, C., et al. *Murmurs of Earth: The Voyager Interstellar Record*. 1978, Random House. The record carried by the Voyager spacecraft includes a wide-ranging selection of Earth's music. [The record itself is now available on CD entitled *Murmurs of Earth* from Warner New Media.]

MYTHOLOGY AND ASTRONOMY

Krupp, E. *Beyond the Blue Horizon: Myths and Legends of the Sun, Moon, Stars, and Planets*. 1991, HarperCollins. Superb collection of astronomical tales from many cultures.

Krupp, E. "Along the Milky Way" in *Mercury*, Nov/Dec. 1991, p. 162. An excerpt from the above book on legends and stories about the Milky Way.

Ridpath, I. *Star Tales*. 1988, Universe Books. A collection of mythology about the constellations, mainly from the Greek and Roman tradition.

PHILATELY (STAMP COLLECTING) AND ASTRONOMY

Crawford, D. "Astronomy and Philately: Collecting Astronomy Stamps" in *Mercury*, Jan/Feb. 1977, p. 17.

Mayernik, A. "Astronomy on Stamps" (a series of articles) in *Sky & Telescope*, 1959, vol. 18, pp. 140, 198, 256, 322, 386, 442; vol. 23, p. 138.

POETRY AND ASTRONOMY

Ackerman, D. "The Poetry of Diane Ackerman" in *Mercury*, Jul/Aug 1978, p. 73.

Byard, M. "Poetic Response to the Copernican Revolution" in *Scientific American*, June 1977.

Carter, T. "Geoffrey Chaucer: Amateur Astronomer?" in *Sky & Telescope*, Mar. 1982, p. 246.

Fraknoi, A. & Friedman, A. "Images of the Universe" in *Mercury*, Mar/Apr 1975, p. 14. On astronomical poetry through history.

Marschall, L. "Modern Poetry and Astronomy" in *Mercury*, Mar/Apr 1983, p. 41.

Marschall, L. "Comets and the Muse" in *Mercury*, Jan/Feb. 1986, p. 10.

Maynard, C. "Robert Frost: Poet of the Night" in *Sky & Telescope*, June 1992, p. 692.

Meadows, A. *The High Firmament*. 1969, Leicester U. Press. A scholarly analysis of astronomical poetry before the modern era.

Weitzenhoffer, K. "Well Versed in Astronomy" in *Sky & Telescope*, Oct. 1990, p. 365 Brief introduction to astronomy in poetry over the centuries.

PSYCHOLOGY AND ASTRONOMY

Abell, G. "Moon Madness" in Abell, G. & Singer, B., eds. *Science and the Paranormal*. 1981, Scribners. Good review of the elusive thesis that there is more aberrant behavior during full moons.

Billig, O. *Flying Saucers, Magic in the Skies: A Psychohistory*. 1982, Schenkman. A psychological examination of the UFO phenomenon and the true believers.

Cantrill, H. *The Invasion from Mars: A Study in the Psychology of Panic*. 1940, Harper Torchbook. About the famous 1938 Orson Welles radio dramatization of "War of the Worlds" and its effects.

Culver, R., et al. "Moon Mechanisms and Myths: A Critical Appraisal of Explanations of Purported Lunar Effects on Human Behavior" in *Psychological Reports*, vol. 62, p. 683 (1988).

Kelly, I., et al. "The Moon Was Full and Nothing Happened" in *Skeptical Inquirer*, Winter 1985-86, vol. 10, p. 129.

Peebles, C. *Watch the Skies: A Chronicle of the Flying Saucer Myth.* 1994, Smithsonian Institution Press. Excellent analysis of the UFO movement and the reasons for its popularity despite the lack of even a shred of evidence.

Restle, F. "The Moon Illusion Explained on the Basis of Relative Size" in *Science*, Vol. 167, p. 1092 (Feb. 20, 1970).

Rotton, J. & Kelly, I. "The Lunacy of It All: Lunar Phases and Human Behavior" in *Mercury*, May/June 1986, p. 1988.

Saunders, F. "The Moon Illusion" in *Mercury*, Mar/Apr 1976, p. 20.

Waterman, T. *Animal Navigation.* 1989, Scientific American Library, W. H. Freeman.

RELIGION AND ASTRONOMY

Davies, P. *God and the New Physics.* 1983, Simon & Schuster. A noted physicist and popularizer looks at the origin of the universe in the context of recent discoveries.

Gingerich, O. "How Galileo Changed the Rules of Science" in *Sky & Telescope*, Mar. 1993, p. 32. On his trial and relations with the Vatican; and his recent pardon.

Lovi, G. "Some Recent Ideas on the Star of Bethlehem" in *Sky & Telescope*, Dec. 1984, p. 536.

Russell, R., et al. *Physics, Philosophy, and Theology: A Common Quest for Understanding.* 1988, Vatican Observatory. Science, speculation, and religious ideas, grappling with notions of God in light of modern scientific discoveries.

SCIENCE FICTION AND ASTRONOMY

Dubeck, L., et al. *Fantastic Voyages: Learning Science Through Science Fiction Films.* 1994, American Institute of Physics. Quick skim of science and a number of films.

Fraknoi, A. "Science Fiction Stories with Reasonable Astronomy" in *Mercury*, Jan/Feb. 1990, p. 26. An annotated reading list.

Freitas, R. "Alien Skies" in *Astronomy*, Apr. 1982, p. 90. What the sky would look like on other planets, real and imaginary.

Lark, N. "Astronomy in Science Fiction" in *Mercury*, May/Jun 1976, p. 16.

Nahin, P. *Time Machines: Time Travel in Physics, Metaphysics, and Science Fiction.* 1993, American Institute of Physics. An exhaustive study of time travel ideas & stories.

Nicholls, P., et al. *The Science in Science Fiction.* 1983, A. Knopf.

Taubes, G. "Profile of Gregory Benford" in *Discover*, Aug. 1983, p. 66. Benford is a physicist who writes superb, scientifically correct science fiction.

SOCIETY AND ASTRONOMY: A SAMPLING OF ISSUES

Beatty, J. "Robert Haag: Rock Star" in *Sky & Telescope*, July 1993, p. 18. On a controversial dealer in meteorite samples.

Chaisson, E. *The Hubble Wars.* 1994, Harper Collins. The political and other struggles behind the project.

Maranto, G. "Stonehenge: Can It Be Saved?" in *Discover*, Dec. 1985, p. 60. On what tourism is doing to the ancient monument.

Robinson, L. "Tough Times for Astronomers in the Former Soviet Union" in *Sky & Telescope*, Sep. 1992, p. 254.

Rubin, V. "Women's Work: Women in Modern Astronomy" in *Science '86*, Jul/Aug. 1986, p. 58. On the difficult history of getting women equal access.

Trimble, V. & Elson, R. "Astronomy as a National Asset" in *Sky & Telescope*, Nov. 1991, p. 485.

SPORTS AND ASTRONOMY

Sagan, C. *The Cosmic Connection.* 1973,

Doubleday. Chapter 15 has a wonderful description of what it would be like to play baseball on the moons of Mars.

Slavsky, D. "The Astrophysics of Baseball: The Game on Earth and Other Planets" in *Mercury*, Sep/Oct. 1992, p. 160.

UFO'S [SEE PSYCHOLOGY]

MISCELLANEOUS TOPICS

Millman, P. "Names on Other Worlds" in *Sky & Telescope*, Jan. 1984, p. 23. How names are assigned to celestial objects.

Molnar, M. "The Coins of Antioch" in *Sky & Telescope*, Jan. 1992, p. 37.

Parkyn, B. "Supersense: The Sidereal Eye" in *Sky & Telescope*, June 1994, p. 30. How the human eye could be redesigned to make it better for doing astronomy.

Schaefer, B. "The Astrophysics of Suntanning" in *Sky & Telescope*, June 1988, p. 595. A bit technical.

Sinnott, R. "Mars Mania of Oppositions Past" in *Sky & Telescope*, Sep. 1988, p. 244. On cartoons, ads, stories, and attempts to signal Mars.

2. EXAMPLES OF THE INTERACTIONS OF ASTRONOMY AND OTHER FIELDS

LITERATURE

Banville, J. *Doctor Copernicus*. 1976, D. R. Godine. Novelization of the life of the pioneering astronomer.

Banville, J. *Kepler: A Novel*. 1981, D. R. Godine.

Calisher, H. *Mysteries of Motion*. 1983, Doubleday. Takes place aboard a space shuttle of the near future.

Calvino, I. *Cosmicomics and Tau Zero*. 1965, 1967, Collier. Short, allegorical stories using astronomical images to illuminate human foibles.

Digby, J. & Brier, B., eds. *Permutations: Readings in Science and Literature*. 1985, Morrow. An eclectic collection of excerpts and poems, with long sections on astronomy and physics.

Gratzer, W., ed. *A Literary Companion to Science*. 1989, Norton. Excerpts from the writings of scientists, poets, and writers about science.

Hardy, T. *Two on a Tower*. 1895 novel about an astronomer who marries above his own social class.

Lightman, A. *Einstein's Dreams*. 1993, Pantheon. A short novel involving Einstein in 1905 and ideas from modern physics.

McCormach, R. *Night Thoughts of a Classical Physicist*. 1982, Harvard U. Press. A fictional physicist reflects on the great 20th century upheavals in physics.

Oates, J. "Passions and Meditations" in *The Seduction and Other Stories*. 1975, Black Sparrow Press. Effective use of black hole images in a character study.

Pynchon, T. *The Crying of Lot 49*. 1966, Bantam. *Gravity's Rainbow*. 1973, Viking. Complex, challenging novels full of science, especially thermodynamics.

Stoppard, T. *Hapgood*. 1988, Faber. A play with quantum mechanical ideas throughout.

POETRY

Ackerman, D. *The Planets: A Cosmic Pastoral*. 1976, Morrow. Wonderful, complex poems inspired by the solar system. See also her collection *Jaguars of Sweet Laughter*, 1991, Random House.

Gordon, B., ed. *Songs from Unsung Worlds: Science in Poetry*. 1985, Birkhauser Boston. An intriguing collection of modern poems, many about astronomy.

Oles, C. *Night Watches: Inventions on the Life of Maria Mitchell*. 1985, Alice James Books.

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Pack, R. *Before It Vanishes: A Packet for Professor Pagels*. 1989, David R. Godine.

Phillips, R., ed. *Moonstruck: An Anthology of Lunar Poetry*. 1974, Vanguard.

Tomlinson, G. & Trainque, D. *Anthology of Astronomical Poetry*. 1984, Great Lakes Planetarium Assn, c/o David Parker, Tipton Planetarium, 817 S. Main St., Tipton, IN 46072.

Updike, J. *Facing Nature*. 1985, Knopf. Includes poems entitled "The Moons of Jupiter," "Ode to Entropy" and "The Shuttle."

vas Dias, R. *Inside Outer Space*. 1970, Doubleday Anchor. A varied collection of modern astronomy and space poems.

SCIENCE FICTION (A REPRESENTATIVE SAMPLING)

Anderson, P. "Day of Burning" in *Beyond the Beyond*. 1969, Signet. An advanced race tries to mobilize the inhabitants of a planet whose star is about to go supernova.

Asimov, I. "Nightfall" in *Nightfall & Other Stories*. 1969, Fawcett. On a planet in a multiple star system, night comes only once every 2000 years.

Asimov, I, et al., eds. *Comets*. 1986, Signet/NAL. A collection of stories about comets and their interaction with humanity.

Benford, G. *Against Infinity*. 1983, Pocket Books. About terraforming Ganymede.

Benford, G. *In the Oceans of Night*. 1977, Dell. Physicist Benford postulates a universe in which machine intelligences confront organic life. Continues in *Across the Sea of Suns*.

Benford, G. *Timescape*. 1981, Pocket Books. A superb book about time communication, particle physics, and the nature of scientific research; features astronomers such as Fred Hoyle and Geoffrey and Margaret Burbidge as characters.

Benford, G. & Brin, D. *Heart of the Comet*. 1986, Bantam. About a 2061 expedition to Halley's Comet.

Brin, D. "The Crystal Spheres" in *The River of Time*. 1987, Bantam. Advanced races use black holes to bear with the loneliness of a universe in which life is still rare.

Clayton, D. *The Joshua Factor*. 1986, Texas Monthly Press. A novel involving intrigue and neutrinos from the Sun by a noted astrophysicist.

Clarke, A. *2010*. 1984, Ballantine. Sequel to *2001*, featuring life under the ice of Europa, Von Neumann probes, and more.

Clarke, A. "The Wind from the Sun" in *The Wind from the Sun*. 1973, Signet. About the effect of a solar flare on a solar wind "sailing race" of the future.

Clarke, A. *The Hammer of God*. 1993, Bantam. An asteroid threatens to collide with the Earth.

Clement, H. *Mission of Gravity*. 1962, Pyramid. Life on a massive, rapidly rotating planet.

Clement, H. "Uncommon Sense" in *Space Lash*. 1966, Dell. About life-forms with liquid metal blood that "see" by smell.

Davies, P. *Fireball*. 1987, Heinemann. Micrometeorites of antimatter threaten the Earth. Davies is a physicist.

Fodor, R. & Taylor, G. *Impact*. 1979, Leisure Books. A giant meteorite is headed our way; Taylor is a planetary scientist.

Forward, R. *Dragon's Egg*. 1981, Ballantine. Proposes a life-form that can live on the surface of a neutron star. Sequel is called *Starquake*.

Gunn, J. *The Listeners*. 1972, Signet. Good portrayal of a scientifically reasonable search for extraterrestrial life.

Haldeman, J. *The Forever War*. 1974, Ballantine. Award-winning novel of an interstellar war involving concepts from both special and general relativity.

Hipolito, J. & McNelly, W., eds. *Mars, We Love You.* 1971, Pyramid. Eclectic collection of fiction and non-fiction about Mars.

Hoyle, F. *The Black Cloud.* 1957, Signet. Intelligence develops in interstellar dust clouds which can move from star to star.

Moffitt, D. *The Jupiter Theft.* 1977, Ballantine. Aliens left homeless by a supernova explosion come to steal Jupiter's hydrogen for fuel to continue their wanderings.

Niven, L. *Ringworld.* 1972, Ballantine. A novel based on Freeman Dyson's ideas about restructuring solar systems.

Niven, L. *World Out of Time.* 1976, Ballantine. Protagonist uses a supermassive black hole to travel into distant future.

Niven, L. "Flare Time" in *Limits.* 1984, Ballantine. Life on a planet in a binary star system with a flare star.

Pesek, L. *The Earth is Near.* 1970, Dell. About a realistic expedition to Mars and the problems they face.

Pohl, F. *Gateway.* 1977, Ballantine. Enjoyable novel about rotating black holes and "black hole guilt".

Pohl, F. *Man Plus.* 1976, Bantam. Humans are biologically engineered to survive on the Martian surface.

Preiss, B., ed. *The Planets.* 1985, Bantam. A collection of essays by noted astronomers about the planets in the solar system and science fiction stories inspired by our current understanding of each world.

Preiss, B. & Fraknoi, A. *The Universe.* 1987, Bantam. A further collection of essays by leading astronomers and science fiction stories with good science; deals with the realms outside our solar system.

Sagan, C. *Contact.* 1985, Simon & Schuster. Good portrayal of how astronomical research is carried out and an interesting attempt to work out some modern issues between science and religion. The plot concerns the discovery of signals from extraterrestrial intelligence.

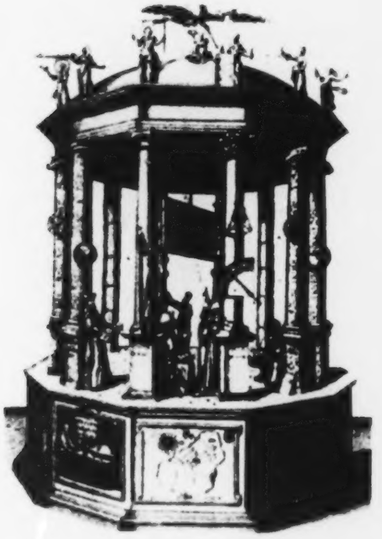
Sheffield, C. *Between the Strokes of Night.* 1985, Baen Books. Proposes a life-form in intergalactic space.

Stith, J. *Redshift Rendezvous.* 1990, Ace Books. Explores what happens when the speed of light is only 10 meters per second.

Tiptree, J. "Love is the Plan the Plan is Death" in Goldin, S., ed. *The Alien Condition.* 1973, Ballantine. Haunting, complex story of a truly alien life-form.

5

RESOURCES AND BIBLIOGRAPHIES



5 RESOURCES AND BIBLIOGRAPHIES

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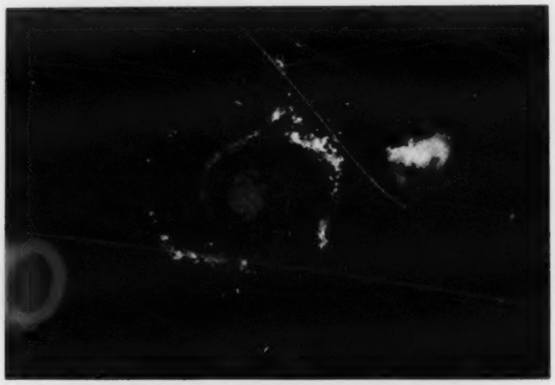

THE UNIVERSE ON A BOOKSHELF: A BASIC ASTRONOMY LIBRARY

by Andrew Fraknoi
Foothill College &
The Astronomical Society of the Pacific

NOTE: This selected list includes magazines and some of our favorite books written for the general public that are scientifically accurate and up-to-date (at the time of their publication). Materials marked with a • are especially appropriate for those just beginning their exploration of the universe. (There are many other excellent books on astronomy that we simply did not have space to list.)

NON-TECHNICAL MAGAZINES

- *Astronomy Magazine* (Kalmbach Publishing, P. O. Box 1612, Waukesha, WI 53187) The largest circulation astronomy publication in the world, very colorful and basic.

Griffith Observer (Griffith Observatory, 2800 E. Observatory Rd., Los Angeles, CA 90027) A small magazine, specializing in historical topics.

Mercury Magazine (Astronomical Society of the Pacific, 390 Ashton Ave., San Francisco, CA 94112) The magazine of the largest public education society in astronomy, with features on astronomy, history, and education.

Odyssey Magazine (Cobblestone Publishing, 7 School St., Peterborough, NH 03458) The only children's magazine in astronomy, full of pictures and activities.

Planetary Report (The Planetary Society, 65 N. Catalina Ave., Pasadena, CA 91106) The colorful magazine of the Society founded by Carl Sagan and others to promote the exploration of the solar system and the search for life elsewhere.

Stardate Magazine (McDonald Observatory, RLM 15.308, University of Texas, Austin, TX 78712) Accompanies the popular public radio program on astronomy.

Sky & Telescope (P.O. Box 9111, Belmont, MA 02178) Found in most libraries, this is the popular astronomy magazine "of record" with many excellent articles on astronomy and amateur astronomy.

Astronomy articles also appear regularly in *Discover*, *Science News*, *National Geographic*, *Scientific American*, and *American Scientist* (the last two are slightly more technical.)

GENERAL INTRODUCTORY BOOKS

- Chaisson, E. *Cosmic Dawn*. 1981, Berkley. Eloquent primer on the evolution of the universe & our place in it. A sequel, *The Life Era*, appeared in 1987 (Atlantic Monthly Press.)

Goldsmith, D. *The Astronomers*. 1991, St. Martin's Press. Companion book to the PBS television series, profiling the work of a number of astronomers who do research at the frontiers of our knowledge.

Malin, D. *A View of the Universe*. 1993, Sky Publishing & Cambridge U. Press. A magnificent book showcasing the images of David Malin, the world's top astronomical photographer.

Preiss, B. & Fraknoi, A., eds. *The Universe*. 1987, Bantam. Collection of introductory articles by noted astronomers and science fiction stories inspired by the science they cover.

Preston, R. *First Light*. 1987, Atlantic Monthly Books. Well-written primer on modern astronomy through the life and work of a few of its finest practitioners (and their work with one of the world's largest telescopes.)

- Ronan, C. *The Universe Explained*. 1994, Henry Holt. A colorful introduction to modern astronomy, in short segments, for beginners.
- Sagan, C. *Cosmos*. 1980, Ballantine paperback. A superbly-written, highly personal survey of astronomy; based on the prize-winning PBS TV series. Good book to start with.

Trefil, J. *Space Time and Infinity*. 1985, Smithsonian Press. A beautiful coffee table book introducing modern astronomy.

- Time-Life's Books' *Voyage Through the Universe* (1988) is a visually stunning series of introductory books about all aspects of modern astronomy, assembled by a team of science writers and researchers; available only from Time-Life, unfortunately.

HISTORIES OF ASTRONOMY

Berendzen, R., et al. *Man Discovers the Galaxies*. 1976, Neale Watson. Excellent history of galactic astronomy and cosmology.

Boorstin, D. *The Discoverers*. 1983, Random House. Brilliant essays on the development of astronomy, geography, and time keeping.

Bronowski, J. *The Ascent of Man*. 1973, Little Brown. Wonderfully written history of scientific ideas, from the public television program; not that much astronomy, however.

Brown, H. *Man and the Stars*. 1978, Oxford U. Press. A history of the interaction of astronomy with timekeeping, navigation, religion/philosophy, etc.

Crowe, M. *Theories of the World from Antiquity to the Copernican Revolution*. 1990, Dover Books. *Modern Theories of the Universe from Herschel to Hubble*. 1994, Dover. Two volume introduction to the high points in the history of astronomical thought.

• Ferris, T. *Coming of Age in the Milky Way*. 1988, Morrow. Eloquent, almost poetic book on the development of our ideas about the universe.

Gingerich, O. *The Great Copernicus Chase*. 1992, Sky Publishing/Cambridge U. Press. Readable essays on a number of historical topics by an outstanding historian.

Hufbauer, K. *Exploring the Sun: Solar Science Since Galileo*. 1991, Johns Hopkins U. Press. A history of how we came to understand the Sun.

• Krupp, E. *Echoes of the Ancient Skies*. 1983, NAL. Introduction to the astronomy of earlier civilizations around world.

• Krupp, E. *Beyond the Blue Horizon*. 1991, Harper Collins. An introduction to the astronomical lore and mythology of many cultures.

Osterbrock, D., et al. *Eye on the Sky*. 1988, U. of California Press. The history of the Lick Observatory, the first major astronomical observing center in the U.S.

Sheehan, W. *Planets and Perception*. 1988, U. of Arizona Press. *Worlds in the Sky*. 1992, U. of Arizona Press. Histories of progress and obstacles in understanding the planets.

Tauber, G. *Man's View of the Universe*. 1979, Crown. Well-illustrated general history.

TELESCOPES AND INSTRUMENTS

Chaisson, E. *The Hubble Wars*. 1994, Harper Collins. Controversial, inside story of some of the political and bureaucratic problems of building the Hubble Space Telescope.

Cohen, M. *In Quest of Telescopes*. 1980, Cambridge U. Press. What it's like to use some of the biggest research instruments in the world.

Davies, J. *Satellite Astronomy*. 1988, Horwood/Wiley. How telescopes in space are revolutionizing astronomy.

Field, G. & Goldsmith, D. *Space Telescope: Eyes Above the Atmosphere*. 1990, Contemporary Books. A clear introduction to the Hubble, but written before the flaw in the mirror was discovered or repaired.

Krisciunas, K. *Astronomical Centers of the World*. 1988, Cambridge U. Press. History of major observatories from ancient days through today.

McLean, I. *Electronic and Computer-Aided Astronomy*. 1989, Horwood/Wiley. Good introduction to the use of CCD's and computers in astronomical observations.

• Tucker, W. & K. *The Cosmic Inquirers*. 1986, Harvard U. Press. Well-written stories of the construction of some of the biggest telescopes on Earth and in space.

THE SOLAR SYSTEM IN GENERAL

Beatty, J., et al. *The New Solar System*, 3rd ed. 1990, Sky Publ. & Cambridge U. Press. A series of occasionally technical review articles by leading experts in planetary science.

• Chapman, C. & Morrison, D. *Cosmic Catastrophes*. 1989, Plenum. Fascinating guide to how impacts, collisions, and violence have shaped the solar system.

Littmann, M. *Planets Beyond: The Outer Solar System*, 2nd ed. 1990, Wiley. Good introduction to Uranus, Neptune, and Pluto.

• Miller, R. & Hartmann, W. *The Grand Tour: A Traveler's Guide to the Solar System*. 1993, Workman. Beautiful primer for the lay reader, by an astronomer and an artist.

• Morrison, D. *Exploring Planetary Worlds*. 1993, Scientific American Library/W. H. Freeman. An illustrated, non-technical survey; excellent book to start with.

Morrison, D. & Owen, T. *The Planetary System*. 1988, Addison-Wesley. A well-written college textbook with extensive information on the planets. Coming soon in a new edition.

• Sagan, C. *Pale Blue Dot*. 1994, Random House. Wonderful, eloquent, up-to-date introduction to planetary exploration, what we have learned and what we can do in the future.

SPECIFIC PLANETS AND MISSIONS

Beebe, R. *Jupiter: The Giant Planet*. 1994, Smithsonian Press. An up-to-date introduction to the largest of the planets.

• Cooper, H. *The Evening Star: Venus Observed*. 1993, Farrar, Straus, Giroux. A journalist covers the excitement and results of the Magellan mission that showed us Venus' surface in detail.

Chaikin, A. *A Man on the Moon*. 1994, Viking Press. Chronicle of the Apollo moon program.

Davis, J. *Flyby*. 1987, Atheneum. A nice summary of the Voyager missions to Jupiter, Saturn, and Uranus.

Hartmann, W. & Miller, R. *The History of the Earth*. 1991, Workman. An astronomer and an artist provide a colorful overview of geology, evolution, and cosmic impacts.

• Hockey, T. *The Book of the Moon*. 1986, Prentice Hall. Fine primer on the closest celestial body.

Strom, R. *Mercury: The Elusive Planet*. 1987, Smithsonian Press. Definitive book on the innermost planet.

Wilford, J. *Mars Beckons*. 1990, Knopf. A science writer looks at the past and possible future exploration of the red planet.

COMETS, ASTEROIDS, AND METEORITES

Bone, M. *Meteors*. 1993, Sky Publishing. A guide and observing manual.

Brandt, J. & Chapman, R. *Rendezvous in Space: The Science of Comets*. 1992, W. H. Freeman. The definitive introduction to the science of comets.

- Levy, D. *The Quest for Comets*. 1994, Plenum Press. A beginner's guide by an enthusiastic amateur comet discoverer.

Norton, O. *Rocks from Space: Meteorites and Meteorite Hunters*. 1994, Mountain Press Publishing. Good handbook for collectors or those who want information.

- Sagan, C. & Druyan, A. *Comet*. 1985, Random House. Beautiful book of comet science and lore, with good background on the solar system.

THE SUN

Note: All of the following books are clear summaries of our present understanding of our star, written by reliable authors:

Frazier, K. *Our Turbulent Sun*. 1983, Prentice-Hall.

Friedman, H. *Sun and Earth*. 1986, W. H. Freeman.

Giovanelli, R. *Secrets of the Sun*. 1984, Cambridge U. Press.

- Kippenhahn, R. *Discovering the Secrets of the Sun*. 1994, J. Wiley.
- Wentzel, D. *The Restless Sun*. 1989, Smithsonian Inst. Press.

ECLIPSES

Harris, J. & Talcott, R. *Chasing the Shadow*. 1994, Kalmbach.

Littmann, M. & Willcox, K. *Totality: Eclipses of the Sun*. 1991, U. of Hawaii Press.

Pasachoff, J. & Covington, M. *Cambridge Eclipse Photography Guide*. 1993, Cambridge U. Press.

STARS, STELLAR EVOLUTION, AND THE INTERSTELLAR MEDIUM

Cohen, M. *In Darkness Born: The Story of Star Formation*. 1988, Cambridge U. Press. Introductory survey by an astronomer.

Friedlander, M. *Cosmic Rays*. 1989, Harvard U. Press. Well-written basic primer on these particles from space.

- Greenstein, G. *Frozen Star*. 1983, Freundlich. Eloquent book about the death of stars and what it is like being an astronomer today.
- Kaler, J. *Stars*. 1992, Scientific American Library/W. H. Freeman. A clear introduction to stellar evolution.

Kaler, J. *Stars and Their Spectra*. 1989, Cambridge U. Press. Detailed guide to spectroscopy and what it teaches us; somewhat technical.

- Kaufmann, W. *Black Holes and Warped Spacetime*. 1979, W. H. Freeman. Good, basic introduction to black holes and the theories behind them.

Kippenhahn, R. *100 Billion Suns*. 1983, Basic Books. Fine popular account of stellar evolution.

- Marschall, L. *The Supernova Story*, 2nd ed. 1994, Princeton U. Press. Excellent guide to exploding stars and Supernova 1987A.

Thorne, K. *Black Holes and Time Warps: Einstein's Outrageous Legacy*. 1994, W. W. Norton. Outstanding introduction to black holes by a world expert.

Verschuur, G. *Interstellar Matters*. 1989, Springer Verlag. A history and modern guide to the material between the stars.

GALAXIES AND QUASARS

- Dressler, A. *Voyage to the Great Attractor*. 1994, Knopf. Personal story of how extragalactic astronomy is done today, focusing on discovery of large-scale structure.

Henbest, N. & Couper, H. *The Guide to the Galaxy*. 1994, Cambridge U. Press. Clear, wonderfully illustrated guide to our Milky Way Galaxy and its contents.

Hodge, P. *Galaxies*. 1986, Harvard U. Press. A clear introduction by a noted astronomer.

Parker, B. *Colliding Galaxies: The Universe in Turmoil*. 1990, Plenum. A nontechnical review of extragalactic astronomy, with a focus on galaxies that merge.

Wright, A. & H. *At the Edge of the Universe*. 1989, Horwood/Wiley. Also a summary of extragalactic astronomy, but especially good on quasars and galaxy surveys.

Many of the books on cosmology also have good discussions of galaxies and quasars.

BOOKS ON DARK MATTER

Each of the following books gives a good overview of how we came to understand the existence of dark matter and of the ongoing quest to determine what it is made of:

- Bartusiak, M. *Through a Universe Darkly*. 1993, Harper Collins.
- Krauss, L. *The Fifth Essence: The Search for Dark Matter*. 1989, Basic Books.

Trefil, J. *The Dark Side of the Universe*. 1988, Scribners.

Tucker, W. & K. *The Dark Matter*. 1988, Morrow.

COSMOLOGY: THE ORIGIN AND EVOLUTION OF THE UNIVERSE

- Barrow, J. *The Origin of the Universe.* 1994, Basic Books. A quick, basic introduction.

Boslaugh, J. ***Masters of Time: Cosmology at the End of Innocence.*** 1992, Addison-Wesley. A journalist's review of the current status of cosmology.

Cornell, J., ed. ***Bubbles, Voids, and Bumps in Time.*** 1989, Cambridge U. Press. Essays by noted astronomers and physicists about frontier areas, including inflation.

Davies, P. *The Last Three Minutes.* 1994, Basic Books. A concise introduction to the end of things.

- Ferris, T. *The Red Limit*, 2nd ed. 1983, Morrow. Good history of how the large-scale properties of the universe were discovered.

- Gribbin, J. *In Search of the Big Bang.* 1986, Bantam Books. Thorough, readable introduction to our quest for the beginning of the universe, by a British scientist/writer.

Harrison, E. *Cosmology.* 1981, Cambridge U. Press. A graceful and authoritative discussion of many topics, including curved space, cosmic horizons, and cosmological models.

Lemonick, M. *The Light at the Edge of the Universe.* 1993, Villard/Random House. A science writer portrays the turmoil of modern cosmology through the eyes of some of its most skilled practitioners.

Overbye, D. *Lonely Hearts of the Cosmos.* 1991, Harper Collins. Journalist's evocative study of cosmologists, focusing especially on Allan Sandage.

Smoot, G. & Davidson, K. *Wrinkles in Time.* 1993, Morrow. An autobiographical and scientific introduction to the measurements of the radiation "echo" of the big bang.

SEARCHING FOR LIFE IN THE UNIVERSE

- Drake, F. & Sobel, D. *Is Anyone Out There?* 1992, Delacorte Press. Autobiography of the pioneer scientist in this field, with good information on the search.

Goldsmith, D. & Owen, T. *The Search for Life in the Universe*, 2nd ed. 1992, Addison Wesley. The basic introductory textbook about this topic.

Mallove, E. & Matloff, G. *The Starflight Handbook.* 1989, Wiley. A clear, sober introduction to the present and possible technologies for traveling among the stars.

- McDonough, T. *The Search for Extraterrestrial Intelligence.* 1987, John Wiley. A very basic survey, with a light touch.

Sullivan, W. *We Are Not Alone*, 2nd ed. 1993 Dutton/Penguin. An updated version of a classic book about the science and people behind the search, by a veteran journalist.

White, F. *The SETI Factor.* 1990, Walker & Co. A rational evaluation of the many issues about the search.

OBSERVING THE NIGHT SKY

- Berry, R. *Discover the Stars.* 1987, Harmony/Crown. A fine introduction by the former editor of *Astronomy* magazine, with clear maps.

Burnham, R. ***Burnham's Celestial Handbook.*** 1978, Dover. 3-volume, 2,138-page thorough reference guide to objects in the sky.

- Chartrand, M. *Skyguide.* 1982, Golden Press. Good compact handbook for beginners, with good illustrations.

Dickinson, T. *Nightwatch.* 1989, Firefly Books. Spiral bound field guide to observing the sky by a fine writer.

Harrington, P. *Touring the Universe through Binoculars.* 1990, John Wiley.

Harrington, P. *Star Ware: The Amateur Astronomer's Guide to Choosing, Buying, and Using Telescopes and Accessories.* 1994, John Wiley.

Kitt, M. *The Moon: An Observing Guide for Backyard Telescopes.* 1992, Kalmbach. A nicely illustrated manual with background on the Moon.

MacRobert, A. *Star Hopping for Backyard Astronomers.* 1994, Sky Publishing. Guidebook to maneuvering among the stars for serious observers.

Matloff, G. *The Urban Astronomer.* 1991, John Wiley. A guide to observing for those in light-polluted cities.

Moore, P. *Exploring the Night Sky with Binoculars.* 1986, Cambridge U. Press. A friendly introduction with clear instructions.

Pasachoff, J. & Menzel, D. *A Field Guide to the Stars and Planets*, 3rd ed. 1992, Houghton-Mifflin. Updated edition of a classic guide to the sky, full of information and with good new maps.

Reddy, F. & Walz-Chojnacki, G. *Celestial Delights.* 1992, Celestial Arts. Lists events in the night sky from 1993-2001, with good background information.

- Rey, H. *The Stars: A New Way To See Them.* 1976, Houghton Mifflin. A classic introduction to finding your way around the night sky, with superb diagrams. (A children's version is entitled *Find the Constellations.*)

Schaaf, F. *Seeing the Sky: 100 Projects, Activities, and Explorations in Astronomy.* 1990, Wiley.

- Whitney, C. *Whitney's Star Finder*, 5th ed. 1990, Random House. Clear, very simple primer to sky phenomena, updated regularly.

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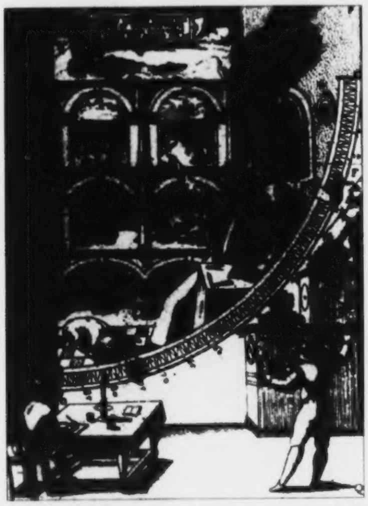

NATIONAL ASTRONOMY EDUCATION PROJECTS: A CATALOG

by Andrew Fraknoi
Foothill College &
Astronomical Society of the Pacific

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Astronomical Society of the Pacific
390 Ashton Ave.
San Francisco, CA 94112

This is an evolving list of projects and programs in astronomy education *to* which anyone from around the U.S. can apply or *from* which anyone can receive materials. It does not include the many worthwhile projects that are designed to serve only one city, one state, or one institution (although we recognize that such programs may nevertheless serve as models for the rest of the country). We very much welcome suggestions and additions for future versions of this list. Please contact the author at the above address or e-mail: fraknoi@admin.fhda.edu.

NOTE: Organizations that are involved with a number of projects are just listed with their names; see the key at the end of the list for their addresses and telephone numbers. We do not list publications such as astronomy magazines, college-level textbooks, or popular books, some of which are listed elsewhere in the notebook.

Table of Contents:

1. Workshops and Training for Teachers of Astronomy
2. Curriculum and Information Materials
3. Audiovisual Materials
4. Computer Materials and Projects
5. Planetarium Education Activities
6. Programs Involving Amateur Astronomers
7. Awards and Grants
8. Newsletters
9. Miscellaneous Projects

Addresses of Frequently Listed Organizations

1. WORKSHOPS AND TRAINING FOR TEACHERS OF ASTRONOMY

American Association of Physics Teachers (AAPT): Has astronomy education sessions aimed at secondary and community college teachers at meetings. Has sponsored a Physics Teacher Resource Agent program to train physics teachers to help other teachers [*see address on last page*]

American Astronomical Society: A-ASTRA Program: Intensive summer workshops for elementary and secondary teachers to become astronomy teaching resource agents in their own communities; offered at several locations around the U.S. Contact: Mary Kay Hemenway, Dept. of Astronomy, University of Texas, Austin, TX 78712 (512-471-6503)

American Astronomical Society (AAS): 2-day "From Black Holes to Blackboards" workshops for teachers, in conjunction with the Society's meetings in different cities [*see AAS address on last page*]

Association of Astronomy Educators (AAE): Puts on astronomy education sessions at meetings of the National Science Teachers Association [*see address on last page*]

Astronomical Society of the Pacific (ASP): 2-day "Universe in the Classroom" workshops for about 200 teachers in grades 3-12, each summer, in conjunction with the Society's meetings [*see address on the last page*]

Astronomical Society of the Pacific (ASP): Project ASTRO: forms and trains ongoing partnerships between astronomers (professional & amateur) and local 4th-9th grade school teachers for class visits [*see address on last page*]

Center for Astrophysics (CfA): Project ARIES Summer Workshops for Elementary School Teachers (grew out of Project STAR and Project SPICA workshops for upper level teachers) [*see address on last page*]

National Science Teachers' Association (NSTA): NEWMAST and NEWEST Workshops, offered at various NASA centers around the country (astronomy is only one part of the workshops' focus) [*see address on last page*]

NSTA also holds large national and regional conventions for science teachers; most of them have astronomy lectures and programs

Project FOSTER: Holds summer workshops and flies K-12 teachers (from selected states) aboard NASA's Kuiper Airborne Observatory. Contact: Edna DeVore, SETI Institute, 2035 Landings Dr., Mountain View, CA 94043 (415-961-6633)

University of Colorado: Two-week summer workshops on

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introductory astronomy for 2- and 4-year college instructors with limited background in astronomy. Contact: Stephen Little, Campus Box 389, University of Colorado, Boulder, CO 80309 (303-492-7627)

2. CURRICULUM AND INFORMATION MATERIALS

Remember this is only a listing of projects, not of all publications. See other resource lists in this Notebook for many recommended activity guides, magazines, and books.

Astronomical Society of the Pacific (ASP): *The Universe at Your Fingertips: An Astronomy Activity and Resource Notebook*, 800+ pages of activities and resources for teachers at all levels, especially grades 4-12. Available through the ASP Catalog.

Astronomical Society of the Pacific (ASP): Information Packets for beginners on astronomical topics, such as black holes, debunking astrology, selecting a first telescope, etc.

Center for Astrophysics (CfA): Project STAR & Project SPICA were NSF-supported programs that developed activity-based curriculum & workbooks for teaching astronomy in secondary schools. Materials can be purchased from Kendall Hunt Publishers, P.O. Box 1840, Dubuque, IA 52004. (The projects also left a legacy of some 200 trained "astronomy resource agent" teachers around the U.S.)

Jet Propulsion Lab: For those who do not live near a NASA center (see below), it is often possible to get NASA lithographs and booklets by writing to: Teaching Resource Center, CS-530, JPL, 4800 Oak Grove Dr., Pasadena, CA 91109. Write on school stationery and indicate what mission or missions you are interested in.

Lawrence Hall of Science (LHS): *Great Explorations in Math & Science* (GEMS), *Planetarium Activities for Student Success* (PASS) are two series of superb hands-on activity guides for teaching astronomy in grades 3-9. Available from the Hall's Eureka store (415-642-1016) or through the ASP catalog [*see addresses at the end*]

NASA: A colorful series of booklets, posters, prints & other materials on space astronomy is available through NASA teacher resource centers around the country. Contact a local NASA center or: Education Division, NASA Headquarters, Washington, DC 20546 for current list of centers. The list of available materials changes constantly. (See also NASA CORE in section 3, and Jet Propulsion Lab above. See also the addresses of organizations listings elsewhere in this notebook.)

National Radio Astronomy Observatory: To get some high school-level radio astronomy activities developed by teachers, write: Sue Ann Heatherly, NRAO, P.O. Box 2, Green Bank, WV 24944 (304-456-2209)

National Science Teachers Association (NSTA): Develops and distributes a range of books and activity collections for teaching astronomy in grades K-12. Ask for their catalog.

New Mexico State University.: Dr. Bernard McNamara is developing a series of writing exercises focused on cosmology. Contact him at: Dept. of Astronomy, Box 30001, Dept. 4500, New Mexico State U., Las Cruces, NM 88003 (505-646-2614) [email: bmcnamar@nmsu.edu]

Pacific Science Center: *AstroAdventures* Curriculum, a series of astronomy activities for grades 3-12, assembled by respected astronomy educator Dennis Schatz, and supported by a NASA Space Grant. Available through the Astronomical Society of the Pacific Catalog.

Project ARTIST: Develops a variety of K-9 activities (some in Spanish, some using multi-cultural ideas) and trains teachers how to use them during summer workshops at the U. of Arizona. Write for list of available materials to: Dr. Larry Lebofsky, Lunar & Planetary Lab, University of Arizona, Tucson, AZ 85721.

SETI Institute: *Life in the Universe* Curriculum Project is developing six interdisciplinary curriculum guides and accompanying materials focusing on a SETI theme at the middle school level. Contact at: 2035 Landings Dr., Mountain View, CA 94043 (415-961-5006)

University of Texas McDonald Observatory: Teacher Kit of poster, activities, and planetary fact sheet for $3. Contact at RLM 15.308, U. of Texas, Austin, TX 78712 (512-471-5285)

Young Astronauts Program: Produces simple activities and materials on space science for youngsters; has many local chapters. Contact at 1308 19th St., NW, Washington, DC 20036 (202-682-1984)

3. AUDIOVISUAL MATERIALS

American Association of Physics Teachers (AAPT): has a modest catalog of audiovisual materials for teaching physics, which includes some astronomy [*see address on last page*]

Astronomical Society of the Pacific (ASP): Produces and distributes slide sets on astronomical topics with extensive booklets of captions and background material, as well as many videotapes and CD-ROM's. Ask for their catalog. (E-mail: asp@stars.sfsu.edu).

Center for Astrophysics (CfA): The Private Universe Project is producing a series of videotapes on student misconceptions in science and strategies for promoting conceptual change. Contact: Nancy Finkelstein (617-496-7676)

Coast Telecourses: Developed 26 half-hour episodes of *Universe: The Infinite Frontier*, a new educational TV show. Contact at: 11460 Warner Ave., Fountain Valley, CA 92708 (714-241-6109)

Finley-Holiday Films: This commercial company has been designated by both the Jet Propulsion Laboratory and the Space Telescope Science Institute to distribute slides and videos to educators at reduced cost. Contact them for a current catalog: 12607 E. Philadelphia St., P.O. Box 619, Whittier, CA 90608 (800-345-6707)

NASA CORE: Distributes a wide range of NASA audiovisual materials at low cost to teachers. Ask for their catalog & updates. Contact at: Lorain County JVS, 15181 Route 58 South, Oberlin, OH 44074 (216-774-1051, ext 293, 294)

Science Graphics: Small company that produces and distributes interesting slide sets in astronomy and earth science. Contact: Richard Norton, P.O. Box 7516, Bend, OR 97702 (503-389-5652)

Space Telescope Science Institute: Has had a strong program of supplying audiovisual materials for educators. Entire education program is under review and is expected to emerge in a new form in 1995. Contact: Anne Kinney or Laura Danly, STScI, 3700 San Martin Dr., Baltimore, MD 21218.

4. COMPUTER MATERIALS OR PROJECTS

American Astronomical Society Working Group on Astronomy Education: Provides an internet bulletin board for announcements and discussion. Contact: Steve Shawl at shawl@kuphsx.phsx.ukans.edu.

Astronomy Software List Project: John Mosley of the Griffith Observatory (and *Sky & Telescope's* primary software reviewer) will supply an up-to-date listing of astronomical software for $2.00. Make check out to John Mosley, 7303 Enfield Ave., Reseda, CA 91335. (It's a great resource.)

The Astronomy Village: CD-ROM, Mac-based supplementary curriculum for 9th grade students. Contact: Craig Blurton, NASA Classroom of the Future, Wheeling Jesuit College, 220 Washington Ave, Wheeling, WV 26003 (304-243-2388)

Exploration in Education (ExInEd): Project directed by Robert Brown at the Space Telescope Science Institute to produce inexpensive Macintosh discs of images (ranging from Hubble Space Telescope images to paintings of an asteroid hitting the Earth) and background material in HyperCard format. Discs are available from the Astronomical Society of the Pacific catalog.

Hands-On Universe Project: trains teachers to do image processing of student-acquired images. Contact: Elizabeth Arsem, Lawrence Berkeley Labs, U. of Calif., Berkeley, CA 94720

Image Processing for Teaching Project: (led by Richard Greenberg at the U. of Arizona) trains teachers to use image processing to stimulate student interest in science. A range of excellent materials is available from the Center for Image Processing, Suite 201, 5343 E. Pima St., Tucson, AZ 85712 (800-322-9884)

Joint Education Initiative: develops CD-ROMs & Internet projects for teachers in geologic and planetary sciences. Contact: Robert Ridky, 3433 A. V. Williams Bldg., U. of Maryland, College Park, MD 20742 (301-405-2324)

Lowell Observatory: Has an innovative interactive exhibit simulating a night at an observatory, with plans available to other institutions. Contact Bill Buckingham, Lowell Obs., 1400 East Mars Hill Rd., Flagstaff, AZ 86001 (602-774-3358).

MicroObservatory (Center for Astrophysics): Developing fully automated, CCD-equipped telescopes with Internet links for remote observing by students. (Ken Brecher at Boston University is also a leader of this project, but contact the Education Dept. at the Center for Astrophysics; address on last page.)

Modern Observational Astronomy Lab Project: Series of lab exercises using an 8-inch telescope and modern instrumentation; developed under the supervision of Daniel Caton at Appalachian State University. Available by anonymous ftp from ili.phys.appstate.edu or 152.10.26.23

NASA Spacelink: An educational bulletin board accessible via modem or internet. For instructions, contact Spacelink, Code CL01, NASA Marshall SFC, Huntsville, AL 35812 (205-544—6360) [*See the sheet on Spacelink in this section of the Notebook.*]

Project CLEA: Produces innovative computer-based astronomy lab exercises for undergraduates on IBM and Mac. Contact at: Dept. of Physics, Gettysburg College, Gettysburg, PA 17325 (717-337-6028)

Remote Access Astronomy Project: computerized telescope and dial-in data distribution (using images from many telescopes) with image processing software & activities. Contact them c/o Dept. of Physics, University of California, Santa Barbara, CA 93106 (805-893-8432) [e-mail: raap@rot.ucsb.edu]

Science Information Infrastructure Project: makes NASA remote sensing data and activities available on-line to museums and schools. Contact Carol Christian, Center for EUV Astrophysics, 2150 Kittredge St., #5030, Berkeley, CA 94720. (510-643-5658) [e-mail: carolc@cea.berkeley.edu]

Many organizations and projects are setting up a "home page" on the World Wide Web about their projects, with files that can be downloaded. For a review of resources on the internet, see the article by David Bruning in the June 1995 issue of *Astronomy* magazine.

5. PLANETARIUM EDUCATION ACTIVITIES

International Planetarium Society: holds conferences, publishes *The Planetarian* magazine, offers special publications and a directory. Contact them c/o Hansen Planetarium, 15 S. State St., Salt Lake City, UT 84111. (There are also active regional organizations of planetarium staff, whose work is described in *The Planetarian.*)

Lawrence Hall of Science (LHS) has offered a series of training workshops for those working with portable planetaria and has a series of activity books for such planetaria (see section 2)

Learning Technologies, Inc.: Small company that makes the *Starlab* inflatable/portable planetaria and trains teachers on how to use them. Also distributes excellent kits of material for high school and college astronomy activities. Contact at: 59 Walden St., Cambridge, MA 02140 (800-537-8703)

Project STARWALK: Offers materials and training for school planetarium activities. Contact: Bob Riddle, Southwest Science H.S., 6512 Wornall Rd., Kansas City, MO 64113 (816-871-0913)

A number of planetaria sell pre-packaged planetarium shows, including the Hayden Planetarium, New York City; the Strassenburgh Planetarium, Rochester, NY; and the Hansen Planetarium, Salt Lake City, Utah.

6. PROGRAMS INVOLVING AMATEUR ASTRONOMERS

American Association of Variable Star Observers: Hands-on Astrophysics Project develops activities and materials for students involving real variable star data. Contact: Janet Mattei, AAVSO, 25 Birch St., Cambridge, MA 02138 (617-354-0484)

American Association of Variable Star Observers: Partnership in Astronomy project links amateur astronomers to school classes (operates in only one area at present) [*see address above*]

Astronomical League (umbrella group of amateur clubs in US): Offers handbook developed by amateurs for teaching astronomy to public. Contact: A.L. Sales Service, c/o Marion Bachtell, 1901 S. 10th St., Burlington, IA 52601. Also has an electronic bulletin board and Messier observing club. Contact John Wagoner, 1409 Sequoia, Plano, TX 75023 (214-422-1886)

Astronomical Society of the Pacific (ASP): Project ASTRO: forms and trains ongoing partnerships between astronomers (professional & amateur) and local 4th-9th grade school teachers for class visits [*see address on last page*]

Astronomy Day: Annual day when amateurs around the country bring telescopes to shopping centers, schools, and other sites to let the public view the sky. Co-sponsored by many organizations. Contact: Gary Tomlinson, Public Museum, 54 Jefferson SE, Grand Rapids, MI 49503 (616-456-3987)

7. AWARDS OR GRANTS FOR ASTRONOMY EDUCATION

American Astronomical Society (AAS): The Annenberg Foundation Prize of the AAS is given for a lifetime of contributions to astronomy education (offered since 1992). Contact them to get the name of the current Chair of the Annenberg Prize committee [*See address on last page*]

Astronomical Society of the Pacific (ASP): The Klumpke-Roberts Award is given each year for a lifetime of contributions to the public understanding of astronomy (offered since 1974). Contact the Society for nomination guidelines.

Astronomical Society of the Pacific (ASP): The Brennan Award is given each year to an outstanding high school teacher of astronomy (offered since 1993). Write for guidelines.

NASA Astrophysics Division (through the Space Telescope Science Institute): IDEA Grants Program funds small and medium size projects in astronomy education by astronomers. Contact: Project Scientist for Education, STScI, 3700 San Martin Dr., Baltimore, MD 21218 [e-mail: idea@stsci.edu]

National Science Foundation: Offers grants for projects in science education through various education and training programs. Write for brochures about current programs and grant guidelines to: NSF Directorate for Education & Human Resources, 4201 Wilson Blvd., Arlington, VA 22230 (703-306-1600).

Slipher Fund of the National Academy of Sciences: supports small grants for innovative astronomy education projects around the country. Contact: Dennis Schatz, Pacific Science Ctr., 200 Second Ave. N, Seattle, WA 98109 (206-443-2886) [e-mail: schatz@pacsci.org]

8. NEWSLETTERS

Astronomical Society of the Pacific (ASP): Publishes free quarterly "Universe in the Classroom" newsletter for grades 3-12 teachers; co-sponsored by several other organizations. Requests must be sent on school stationery [*see address at end*]

Association of Astronomy Educators (AAE): Has a newsletter on teaching astronomy for its members [*see address at end*]

NASA: *Educational Horizons* Free newsletter brings news of NASA science and education activities to teachers. Contact: NASA Headquarters, Education Division, Code FE, Washington, DC 20546

9. MISCELLANEOUS PROJECTS

Astronomical Society of the Pacific (ASP): Universe Expo, a weekend "festival" of astronomy talks, seminars, and exhibits for the public, held in conjunction with the Society's annual meeting

Boston Museum of Science: *Touch the Stars* is a tactile astronomy book in Braille for the visually impaired. Contact Noreen Grice, Museum of Science, Science Park, Boston, MA 02114 (617-589-0439)

Center for Astrophysics (CfA): Workshop on Research Techniques for Undergraduate Faculty at Small Observatories, offered to help instructors at 2- or 4-year teaching colleges who want to get students involved in hands-on observing. Contact Steve Leiker at the CfA address at end.

Coalition for Earth Science Education: An umbrella group of organizations interested in encouraging the teaching of earth science, which includes astronomy. Contact: Frank Ireton, AGU, 2000 Florida Ave., NW Washington, DC 20009 (202-462-6910)

Committee for the Scientific Investigation of Claims of the Paranormal (CSICOP): Group of scientists, educators, magicians, & skeptics that informs the public about the scientific perspective on such pseudosciences as astrology, psychic power, or the face on Mars. They publish the excellent *Skeptical Inquirer* magazine. Contact at: Box 703, Buffalo, NY 14226 (716-636-1425)

Earth and Sky Radio Series: a 2-minute daily radio series on astronomy and earth science. Highlights tape available. Contact at: P.O. Box 2203, Austin, TX 78703 (512-477-4441)

International Dark-Sky Association: Non-profit organization devoted to educating the public about the danger and waste of light pollution. Good information packets available. Contact: David Crawford, 3545 N. Stewart, Tucson, AZ 85716.

Mt. Wilson Observatory: Telescopes in Education Project allows classes to do remote observing with a 24-inch telescope using a computer and modem in their school. While the remote observing costs money for amateurs or colleges, NASA is funding the program free for schools on an experimental basis. Contact: TIE, Box 24, Mt. Wilson, CA 91023 (818-395-7579)

National Optical Astronomy Observatories: Has inaugurated a new program in education, with a number of projects that are just getting under way. Some are local to Arizona, others will be on the internet. For currents status, contact Suzanne Jacoby, NOAO, P.O. Box 26732, Tucson, AZ 85726.

National Undergraduate Research Observatory: A 31-inch telescope near Flagstaff, AZ and a consortium of colleges to operate it. Contact: Kathy Eastwood, Physics & Astronomy, N. Arizona Univ., P.O. Box 6010, Flagstaff, AZ 86011 (602-523-2661)

Smithsonian Astrophysical Observatory: Summer Intern Program for Undergraduates; especially targeted at women/minority students from small colleges. Contact: Kim Dow, CfA, 60 Garden St., Cambridge, MA 02138 (617-496-7586)

University of Arizona Astronomy Camps: Summer programs for youngsters and adults. Contact Don McCarthy, Steward Obs., U. of Arizona, Tucson, AZ 85721 (602-621-4079)

University of Texas McDonald Observatory: *StarDate* 2-minute daily radio program, broadcast on many stations, available on CD's or tape. A new Spanish-language version called *Universo* debuted in April 1995. Contact at RLM 15.308, U. of Texas, Austin, TX 78712 (512-471-5285)

ADDRESSES OF ORGANIZATIONS LISTED SEVERAL TIMES ABOVE:

American Association of Physics Teachers, 1 Physics Ellipse, College Park, MD 20740 (301-209-3300)

American Astronomical Society, Suite 400, 2000 Florida Ave., Washington, DC 20009 (202-328-2010)

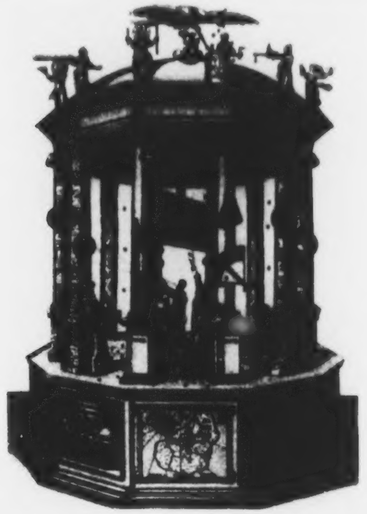
Association of Astronomy Educators, c/o Katherine Becker, 5103 Burt St., Omaha, NE 68132

Astronomical Society of the Pacific, 390 Ashton Ave., San Francisco, CA 94112 (415-337-1100)

Center for Astrophysics, Education Dept, MS 71, 60 Garden St., Cambridge, MA 02138 (617-495-9798)

Lawrence Hall of Science, University of California, Berkeley, CA 94720

National Science Teachers' Association, 1840 Wilson Blvd., Arlington, VA 22201 (703-243-7100)



SELECTED RESOURCES FOR TEACHING ASTRONOMY

by **Andrew Fraknoi**
Foothill College &
The Astronomical Society of the Pacific

©1995 Astronomical Society of the Pacific,
390 Ashton Ave., San Francisco, CA 94112.

NOTE: This list is divided into three sections. The first offers books and articles that list or review written, audiovisual, and computer-based astronomy resources for K-12 teachers or astronomers who are visiting K-12 classrooms. The second contains compilations and examples of hands-on activities for teaching astronomy at this level. The third lists books and articles that describe or discuss the teaching of astronomy, student reasoning ability, and specific projects for improving astronomy education.

We have restricted the listings to materials that are widely available or published by educational or scientific organizations of long standing.

1. RESOURCES

A. Books on Teaching Resources

Friedman, A., et al. *Planetarium Educator's Workshop Guide, 2nd ed.* 1990, Lawrence Hall of Science, Astronomy Education Program, U. of California, Berkeley, CA 94720. Includes both resources and activities for teachers with access to a planetarium.

Gibson, B. *The Astronomer's Sourcebook.* 1992, Woodbine House, 5615 Fishers Lane, Rockville, MD 20852. A guide to astronomical equipment, publications, planetaria, organizations, events, etc.

Harrington, P. *Star Ware.* 1994, John Wiley. A guide written by an avid amateur for choosing, buying, and using telescopes and accessories.

Makower, J., ed. *The Air And Space Catalog: The Complete Sourcebook to Everything in the Universe.* 1989, Tilden/Random House. Lists hundreds of places to get information and teaching aids.

Saul, W. & Newman, A. *Science Fare: An Illustrated Guide and Catalog of Toys, Books, and Activities for Kids.* 1986, Harper & Row. Resources for school teachers in many areas.

Sneider, C., et al. *Planetarium Activities for Student Success.* 1990-4, Lawrence Hall of Science, University of California, Berkeley, CA 94720. Volume 3 of this very useful series of activity booklets is a resource guide to materials for astronomy teaching.

Regular book and resource reviews appear in *Sky & Telescope, Mercury, Astronomy,* and other astronomy magazines, as well as *The Science Teacher, The Physics Teacher,* and *Science Books & Films.*

B. Articles on Teaching Resources (except computer software)

Bruning, D. "Charting a Path Through the Night Sky" in *Astronomy,* Oct. 1993, p. 74. Comparative review of star atlases and guides.

Carter, C. "Sources for Space Science Projects" in *Science Books and Films,* Jan/Feb. 1990, p. 148.

Coyle, H. "Astronomy Texts from Abell to Zeilik" in *Sky & Telescope,* Nov. 1987, p. 487.

Fraknoi, A. "Science Fiction Stories with Good Astronomy" in *Mercury,* Jan/Feb. 1990, p. 26.

Fraknoi, A. "Scientific Responses to Pseudoscience Related to Astronomy" in *Mercury,* Sep/Oct. 1990, p. 144. Resources for debunking astrology, UFO's, ancient astronauts, etc.

Fraknoi, A. & Freitag, R. "Women in Astronomy: A Bibliography" in *Mercury,* Jan/Feb. 1992, p. 46. Part of a special issue on women in astronomy.

Kruglak, H. "Resource Letter: Laboratory Exercises for Elementary Astronomy" in *American Journal of Physics,* vol. 44, p. 828 (1976).

C. Articles on Computer-based Resources

Bruning, D. "Computers and Astronomy" in *Astronomy,* May 1994, p. 58. A thorough guide to astronomy software and how it can be used.

Goldman, S. "Browsing Computer Bulletin Boards" in *Sky & Telescope,* March 1994, p. 84.

Mosley, J. "The CD-ROM Comes of Age" in *Sky & Telescope,* July 1992, p. 77. Reviews of astronomical CD-ROM's by S&T's excellent software reviewer.

Mosley, J. "Exploring the Sky on Computer" in *Sky & Telescope*, June 1990, p. 650; Mar. 1992, p.318. Reviews of planetarium type programs; regularly updated in Mosley's column in the magazine.

Mosley, J. & Fraknoi, A. "Computer Software in Astronomy" in *Mercury*, May/June 1991, p. 87. Annotated listing, organized by types.

Sneider, C. & Berndt, H. "A Galaxy of Astronomy & Space Software" in *Technology & Learning*, May/June 1994, p. 20. Reviews of many software packages from a K-12 teaching perspective.

Trivette, D. "Stargazer's Delight: Six Programs for Astronomy Hobbyists" in *PC Magazine*, July 1993, p. 546. Good comparative reviews.

2. ACTIVITIES

A. Selected Books of Classroom or Family Activities

Apfel, N. *Astronomy Projects for Young Scientists.* 1984, Arco.

Ball, N., et al., eds. *Project SPICA: A Teacher Resource to Enhance Astronomy Education.* 1994, Kendall-Hunt. A collection of 43 astronomy activities at the 6th - 12th grade level from a project at the Center for Astrophysics.

Bonnet, R. & Keen, G. *Space and Astronomy: 49 Science Fair Projects.* 1992, Tab Books.

Braus, J., ed. *Astronomy Adventures.* A special issue of Ranger Rick's NatureScope, from the National Wildlife Federation, 1412 Sixteenth St., NW, Washington, DC 20036. An 80-page guide to elementary school activities.

Coyle, H, et al. *Project STAR: The Universe in Your Hands.* 1993, Kendall Hunt. A high school astronomy supplement, full of sophisticated hands-on projects.

DeBruin, J. & Murad, D. *Look to the Sky: An All Purpose Interdisciplinary Guide to Astronomy.* 1988, Good Apple. Activities for grades 4-12 of varying quality and level.

Friedman, A. et al. *Planetarium Educator's Workshop Guide.* [See section 1 above.]

Gardner, R. *Projects in Space Science.* 1988, Messner.

Greenleaf, P. *Experiments in Space Science.* 1981, Arco.

Moeschl, R. *Exploring the Sky: Projects for Beginning Astronomers, 2nd ed.* 1993, Chicago Review Press. An eclectic collection of 60+ astronomy activities of varying quality.

Schatz, D. *Astronomy Activity Book.* 1991, Simon & Schuster. Basic observing activities for upper elementary and junior high level.

Schatz, D. *The Return of the Comet: An Activity Book for Skywatchers 9-14.* 1985, Pacific Science Ctr., 200 Second Ave., N., Seattle, WA 98109.

Schatz, D. & Cooper, D. *Astro Adventures: An Activity Based Astronomy Curriculum.* 1994, Pacific Science Center. Superb compilation of some of the very best K-12 astronomy activities; many of them are featured in *The Universe at Your Fingertips.*

Smith, P. *Project Earth Science: Astronomy.* 1992, National Science Teachers' Association. Collection of activities & resources for middle schools.

Sneider, C., et al. *Planetarium Activities for Student Success.* 1990-4, Lawrence Hall of Science, University of California, Berkeley, CA 94720. A wonderful series of 12 booklets on activities for portable planetaria, many of which can be used very well in the regular classroom.

Sneider, C. *Earth, Moon, and Stars: A Teacher's Guide for Grades 5-9.* Sutter, D., et al. *The Moons of Jupiter: A Teacher's Guide for Grades 4-9.* 1986, 1993, GEMS Program, Lawrence Hall of Science, U. of California, Berkeley, CA 94720. Excellent activity-oriented workbooks; part of a series of good *Great Explorations in Math & Science* guides in various fields.

Wooley, J. *Voyages through Space and Time: Projects for VOYAGER* [Software for the Macintosh]. 1992, Wadsworth. A series of high school or college level activites with this popular program that can show the sky at any time from any place on Earth.

B. Selected Articles on Classroom Activities

Chandler, D. "An Expanding Universe in the Classroom" in *Physics Teacher*, Feb. 1991, p. 103.

Dodson, S. "Simple Classroom Telescopes" in *Sky & Telescope*, Mar. 1991, p. 311. Simple designs you can build and how to use them in the classroom.

Harris, J. & Watson, F. "Some Astronomy Exercises for a High School Physics Course" in *Physics Teacher*, vol. 6, p. 394 (1968).

Kaufman, S. "Astronomy Spectra Experiments for Nonscience Students" in *Physics Teacher*, vol. 20, p. 170 (1982).

Lamark, D. "Set Your Class in Celestial Motion" in *Science Teacher*, Sep. 1989, p. 59. Having students enact and plot rotation, revolution, and retrograde motion.

Lamb, W. "Build-It-Yourself Astronomy" in *Science Teacher*, Mar. 1983, p. 16. On building a cross-staff and quadrant and using them.

Lebofsky, M. "A Skunk Is in the Sky or Is It a Plow?" in *Science Scope*, Mar. 1994, p. 26. On some activities for lower grades using sky mythology.

MacRobert, A. "Astronomy with a $5 Telescope" in *Sky & Telescope*, Apr. 1990, p. 384. On the Project STAR telescope kit and activities.

Murphy, R. & Kwasnoski, J. "Years, Days, and Solar Rays" in *Science Teacher*, Oct. 1983, p. 28. Measuring sunlight at different seasons.

Oates, C. & Hockey, T. "Twinkle Twinkle Little Star" in *Science Teacher*, Oct. 1993, p. 63. A scavenger hunt activity for astronomy information.

Riddle, B. "The Seasonal Sun: Rotating and Revolving through the Seasons" in *Science Teacher*, Oct. 1988, p. 29. Uses worksheets and computer software.

Sadler, P. "Projecting Spectra for Classroom Investigation" in *Physics Teacher*, Oct. 1991, p. 423.

Sarton, E. "Measuring the Moon's Orbit" in *Physics Teacher*, vol. 18, p. 504 (1980).

Zeilik, M. "An Expanding Universe Demonstration" in *American Journal of Physics*, vol. 50. p. 571 (1982).

C. Selected Articles on Sky Observing Activities

Bagnall, P. "Observing the Naked Eye Sky Glows" in *Astronomy*, June 1988, p. 46. On aurorae, zodiacal light, etc.

Bunge, R. "Nightscapes: Photos with Only Camera & Tripod" in *Astronomy*, June 1992, p. 72.

Burnham, R. "Observing the Sun" in *Astronomy*, Aug. 1984, p. 51.

Chaikin, A. "A Guided Tour of the Moon" in *Sky & Telescope*, Sep. 1984, p. 211.

Clark, G. "Starting an Astronomy Club" in *Astronomy*, Oct. 1981, p. 52.

Coco, M. "Staging a Moon Shot" in *Astronomy*, Aug. 1992, p. 62. Hints on photographing the moon for beginners.

Dyer, A. "Seeking the Best 35-mm Camera for Astrophotography" in *Astronomy*, Sep. 1993, p. 74; "Taking Pictures with Your Telescope" in *Astronomy*, Dec. 1992, p. 66.

Dyer, A. & Talcott, R. "Celestial Sights of the Future" in *Astronomy*, Aug. 1993, p. 64. Best sky events from 1994 to 2017.

Fortier, E. "An Observer's Guide to Sunspots" in *Astronomy*, May 1991, p. 62.

Harrington, P. "The Ten Best Double Stars" in *Astronomy*, July 1989, p. 78.

Hill, R. "Equipped for Safe Solar Viewing" in *Astronomy*, Feb. 1989, p. 66.

King-Hele, D. & Erberst, R. "Observing Artificial Satellites" in *Sky & Telescope*, May 1986, p. 457.

Levy, D. "Discovering Binocular Astronomy" in *Astronomy*, Dec. 1985, p. 44.

Lewis, S. "Eye on Io" in *Science Teacher*, May 1985, p. 42. Observing Jupiter's moons and figuring out their motion.

Ling, A. "An Eye on the Deep Sky: Objects Visible to the Naked Eye" in *Astronomy*, Jan. 1992, p. 68. 40 interesting objects you don't need a telescope to see.

Loudon, J. "Learning the Sky by Degrees" in *Astronomy*, Dec. 1986, p. 54. On angular measurement on the sky.

MacRobert, A. "Close-up of a Star" in *Sky & Telescope*, May 1985, p. 397. Hints for observing the Sun.

MacRobert, A. "An Observer's Guide to Saturn" in *Sky & Telescope*, Nov. 1993, p. 52.

MacRobert, A. "Photography Through a Telescope" in *Sky & Telescope*, Dec. 1986, p. 569.

Morel, P. "Drawing the Sun and the Moon" in *Sky & Telescope*, Apr. 1988, p. 404.

Olivarez, J. "Seeing the Most on Jupiter" in *Astronomy*, Mar. 1992, p. 85.

Porcellino, M. "Polar Aligning Your Telescope" in *Astronomy*, May 1992, p. 69.

Russo, R. "Astronomy By Day" in *Science Teacher*, Mar. 1982, p. 30; May 1983, p. 32. On measuring sunspots.

Sessions, L. "Observing Planets in the Daytime" in *Astronomy*, Jan. 1981, p. 40.

Sinnott, R. "Tracing Earth Satellites on Your Home Computer" in *Sky & Telescope*, May 1986, p. 501.

3. IDEAS AND PROGRAMS

A. Books on Astronomy Education

Berendzen, R., ed. *International Conference on Education In and History of Modern Astronomy.* 1972, New York Academy of Science. Published as vol. 198 of the *Annals of the NY Academy of Science*, with useful articles on education at a variety of levels.

Dubeek, L., et al. *Fantastic Voyages: Learning Science Through Science Fiction Films.* 1994, American Institute of Physics Press. Suggestions for using student interest in science fiction films for teaching concepts in physical science; high school or college level.

Hunt, J., ed. *Cosmos: An Educational Challenge.* 1986, European Space Agency. Proceedings of a European conference on education at various levels, held in Denmark in 1986.

Pasachoff, J. & Percy, J., eds. *The Teaching of Astronomy.* 1990, Cambridge U. Press. Proceedings of an international colloquium on astronomy education in the US and elsewhere; probably the best single source on astronomy education.

Pennypacker, C., ed. *Workshop on Hands-on Astronomy for Education.* 1992, World Publishing. Projects emphasizing computers and small telescopes.

B. Articles on Astronomy Education in General

Annett, C. "The Planetarium: A Sky for All Seasons" in *Mercury*, Nov/Dec. 1979, p. 136. An overview of planetaria.

Atkin, J. "Teaching Concepts of Modern Astronomy to Elementary-School Children" in *Science Education*, vol. 45, p. 54 (1961).

Baxter, J. "Children's Understanding of Familiar Astronomical Events" in *International Journal of Science Education*, vol. 11, p. 502 (1989).

Bishop, J. "U.S. Astronomy Education: Past, Present, and Future" in *Science Education*, vol. 61, p. 295 (1977, no. 3). Interesting review, with good historical accounts.

Bracher, K. "The Stars for All: The Centennial History of the Astronomical Society of the Pacific" in *Mercury*, Sep/Oct. 1989, the entire issue. Describes many of the educational activities of the Society over the years.

Cole, S. "Astronomy in our Schools" in *Astronomy*, Sep. 1988, p. 36. Overview of programs and projects.

Fraknoi, A. "Hearing the Music of the Spheres: Informal Astronomy Education" in Druger, M., ed. *Science For the Fun of It*. 1988, National Science Teachers Association. A review of astronomy learning outside the formal classroom.

Fraknoi, A. "Astronomy Education: The State of the Art" in *Mercury*, Jan/Feb. 1977, p.9. Report on a 1976 symposium on astronomy education.

Friedman, A. "Alternative Approaches to Planetarium Programs" in *Mercury*, Jan/Feb. 1973, p. 12. One of the first suggestions in print of the idea of participatory planetarium programs.

Haupt, G. "First Grade Concepts of the Moon" in *Science Education*, vol. 32, no. 4, p. 258 (Oct. 1948); vol. 34, no. 4, p. 224 (Oct. 1950).

Klein, A. "Children's Concepts of Earth and Sun: A Cross-Cultural Study" in *Science Education*, vol. 65, #1, p. 95 (1982).

Lightman, A. & Sadler, P. "The Earth is Round? Who Are You Kidding?" in *Science and Children*, Feb. 1988, p. 24. On studies of how children reason and learn.

Lightman, A. & Sadler, P. "Teacher Predictions Versus Actual Student Gains" in *Physics Teacher*, Mar. 1993. Results from Project STAR showed that teachers are often off the mark in predicting how much students would learn.

Lockwood, J. "Creating Gender-Friendly Astronomy Classrooms" in *Mercury*, Jan/Feb. 1994, p. 25. High school teacher discusses how to encourage girls in science.

Lockwood, J. "Latching on to the Whirlwind: The Changing Face of Astronomy Education" in *Mercury*, Mar/Apr. 1993, p. 56. On several innovative projects.

Norton, O. "Will Planetariums Become Extinct?" in *Sky & Telescope*, Dec. 1985, p. 534. On the history and current state of planetaria in the U.S.

Petersen, C. "There's No Place Like Dome" in *Sky & Telescope*, Sep. 1989, p. 255. On astronomy education at several planetaria and science centers.

Reed, G. "Is the Planetarium a More Effective Teaching Device than the Combination of the Classroom Chalkboard and Celestial Globe?" in *School Science and Mathematics*, vol. 70, no. 6, p. 487 (June 1970); vol. 72, no. 5, p. 368 (May 1972); vol. 73, no. 7, p. 553 (Oct. 1973).

Sagan, C. "Why We Need to Understand Science" in *Mercury*, Mar/Apr. 1993, p. 52. Eloquent overview of the need for public education in astronomy.

Schatz, D. & Lawson, A. "Effective Astronomy Teaching: Intellectual Development and Its Implications" in *Mercury*, Jul/Aug. 1976, p. 6. Clear introduction to how students reason and why educators at all levels need to understand more about the process.

Sneider, C. & Pulos, S. "Children's Cosmographies: Understanding the Earth's Shape" in *Science Education*, vol. 67, #2, p. 205 (1983). Useful for illuminating how youngsters think through problems in physical science in general.

Sneider, C., et al. "Understanding the Earth's Shape and Gravity" in *Learning*, vol. 14, no. 6, p. 43 (Feb. 1986).

Trimble, V. & Elson, R. "Astronomy as a National Asset" in *Sky & Telescope*, Nov. 1991, p. 485. Outlines some of the ways astronomy helps science education in the US.

Wall, C. "A Review of Research Related to Astronomy Education" in *School Science and Mathematics*, vol. 73, no. 8, p. 653 (Nov. 1973).

Yuckenberg, L. "Children's Understanding of Certain Concepts of Astronomy in First Grade" in *Science Education*, vol. 46, no. 2, p. 148 (Mar. 1962).

C. Articles on Specific Projects to Improve Astronomy Education

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Courtesy Harvard College Observatory Archives

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Women in Astronomy: An Introductory Bibliography

by Andrew Fraknoi
Foothill College &
The Astronomical Society of the Pacific
&
Ruth Freitag
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Courtesy of Harvard College Observatory Archives

Annie J. Cannon

URANIA'S HERITAGE:
A HISTORICAL INTRODUCTION TO WOMEN IN ASTRONOMY

Andrea K. Dobson
and
Katherine Bracher
Whitman College

Author's note: Urania was the ancient Greeks' Muse of Astronomy.

'Women astronomers' must seem like an oxymoron to many. Pick up any current textbook on astronomy (nearly all of which are written by men[1]) and examine the index: among the couple of hundred people listed, chances are good that you will find fewer than six or seven women. Is it actually the case that astronomy (or at least 'significant' astronomy) is and always has been done only by men? Hardly. Despite often intimidating social pressures, women have always participated in astronomy. Many women, whose names our students by and large don't find in their textbooks, have made valuable contributions to our deepening understanding of our universe.

The opportunities women have had to participate in astronomy (and, of course, in the sciences generally) have been constrained both by external pressures such as lack of access to education (and lack of access to work and equipment even with education), and by social conditioning that led many brilliant women to question their own worth and abilities. In this article, we want to look briefly at the work of several women astronomers and also at how the opportunities, work, and self-images of women in astronomy have changed over the past two centuries.[2]

CAROLINE LUCRETIA HERSCHEL

Before the widespread accessibility of higher education it was often the case that women (and men, a point that is often overlooked) came to an interest in astronomy by way of a relative. Often women astronomers were assistants to their fathers, husbands, or brothers; such collaboration makes it all too easy to label their work as not particularly original.

One who received some amount of recognition for her assistance was Caroline Lucretia Herschel, born in 1750 in Hanover into a large and musically inclined family. Her mother deemed it appropriate that Caroline receive a minor amount of formal education and a large amount of informal training to equip her to care for her brothers. Her brother William, 12 years her senior, took his musical training and his interest in astronomy to England in 1757; Caroline followed him 15 years later. With some additional formal training Caroline Herschel probably could have pursued an independent singing career; she preferred to give that up to assist and keep house for William.

William's 1781 discovery of Uranus (and the ensuing salary bestowed upon him by King George III) allowed him to devote his entire time to astronomy. While William ground the glass for his telescopes, Caroline fed him by hand; while he observed, she recorded his observations. In 1782 he gave her a small telescope with which she could observe the skies on her own when he was away. On August 1, 1786, Caroline discovered a comet, the first of eight she found over a span of eleven years. Her note to the Secretary of the Royal Society announcing her first discovery is almost apologetic in tone; later announcements are more professional and less self-deprecating.

For her work, the king granted Caroline Herschel an annual pension of 50 pounds, the "first time that a woman had been appointed assistant to the court astronomer." It was also the first time Caroline had ever had any funds of her own to use as she wished. William married in 1788, freeing Caroline from the duties of a housewife. She continued to assist him in his astronomy, however, and to make her own observations as time permitted.

More significant than her comet discoveries was Herschel's work in the reduction and publication of her brother's observations of nebulae. The reduction of position measurements to a common epoch was, to put it mildly, a tedious business. The publications included, following William's death in 1822, A Catalogue of the Nebulae which have been observed by William Herschel in a Series of Sweeps, containing over 2500 positions. For this work Caroline, who had returned to Hanover, received in 1828 a Gold Medal from the Royal Astronomical Society (RAS). William's son John, also a noted astronomer, was president of the RAS at the time and seems to have been quite ambivalent about the award. In writing to notify his aunt, John says "Pray let me be well understood on one point. It was none of my doings. I resisted strenuously. Indeed, being in the situation I actually hold, I could do no otherwise. The Society have done well. I think they might have done better, but my voice was neither asked nor listened to." (In subsequent correspondence he does apologize for offending his aunt.) Caroline was a bit unsure of the matter herself, writing in reply to her nephew that "I felt from the first more shocked than gratified by that singular distinction, for I know too well how dangerous it is for women to draw too much notice on themselves . . . Whoever says too much of me says too little of your father!" Throughout her life she consistently down-played her own work in favor of her brother's.

Herschel kept up, as best she could with failing eyesight, with current astronomy, and frequently received visiting scientists passing through Hanover. In 1835 she and Mary Somerville were elected honorary fellows of the RAS (women, of course, not being permitted to be actual members), and on the occasion of her birthday in 1846 she received a Gold Medal for Science from the king of Prussia. She died the following year at age 97.

MARIA MITCHELL

In the year of Herschel's death a comet was found by a 29-year-old librarian and amateur astronomer. For this discovery Maria Mitchell was awarded a gold medal by the king of Denmark, offered for the first report of a comet that was not visible to the naked eye at the time of its discovery. This catapulted her to a considerable amount of fame, although not so lasting that the Smithsonian Institution felt inclined to include Mitchell in its 1976 exhibition on 200 years of American astronomy.

Mitchell was born in 1818 to a Quaker family on the island of Nantucket. With many of the local men away at sea for long periods, the island women were of necessity quite reliant upon each other, which may have influenced Mitchell's later belief in the work of women's colleges. Her father was interested in astronomy and Maria was assisting him, learning to use a sextant and set a chronometer at an early age. Her later assessment of her own abilities was that she "was born of only ordinary capacity, but of extraordinary persistency." Mitchell's formal schooling came to an end when she was 16. After teaching for about a year, Mitchell was offered the post of librarian at the new Nantucket Atheneum. Since the Atheneum was only open afternoons and Saturday evenings, Mitchell had plenty of time for study and astronomy. Her father's recognition as a good amateur astronomer brought Maria into contact with professional astronomers at places like Harvard and the Smithsonian.

Following Mitchell's comet discovery, she was elected as the first woman member of the American Academy of Arts and Sciences (in 1848 — it would be 95 years before a second was elected) and to the newly formed American Association for the Advancement of Science

(1850). In 1849 Mitchell was employed as a computer (one who performs lengthy mathematical calculations) for the American Ephemeris and Nautical Almanac, calculating (naturally!) positions of the planet Venus; she continued at this occupation for 19 years.

Mitchell's greatest contributions came in the area of women's education. While her comet discovery was not exactly Earth-shattering science, it had brought Mitchell recognition as one of a very few women scientists in the U.S. Thus, in 1865, when Vassar College opened, Mitchell was asked, despite her lack of formal education, to become professor of astronomy and director of the observatory. At this point, concerned about the "half-educated, loose, and inaccurate ways" in which young women seemed to think, Mitchell seems to have made a conscious decision to commit her time to teaching rather than to more prestigious research work. And apparently as a teacher Mitchell was outstanding, highly motivating and demanding painstaking mathematics and careful observations. The Vassar trustees certainly weren't convinced of her worth: Mitchell received a salary of $800, compared to the $2500 received by the male professors.

Despite a lack of good equipment, Mitchell and her students were able to do productive astronomy. She observed several solar eclipses, including travelling to Denver for the notable eclipse of 1878; she followed the changes in sunspots; her regular observations of Jupiter led her to conclude that one sees merely the uppermost clouds of a body composed entirely of clouds, rather than thin clouds above a solid surface as was supposed by current theory; she noted also the differences in appearance among Jupiter's satellites. For her work Mitchell received three honorary degrees: LL.D.s from Hanover College (1853) and Columbia (1887) and a Ph.D. from Rutgers (1870). She also is honored by a small lunar crater which bears her name.

Over the course of her life Mitchell became more and more interested in the cause of women's rights generally and women's science education more specifically. In 1873 she helped found the Association for the Advancement of Women, and served as president of that organization for two years, 1875 and 1876. She chaired the AAW science committee until her death.

Mitchell recognized that her work did not produce incredible advances in theoretical astronomy. She strenuously objected, however, to the suggestion that as women had patently contributed so little to science in the past, they were therefore incapable of doing so in the future. To compare the work, for instance, of Caroline Herschel, busy knitting her brother's socks, to that of Tycho Brahe, provided with an observatory and assistants was simply not fair: "The laws of nature are not discovered by accident, theories do not come by chance, even to the greatest minds; they are not born of the hurry and worry of daily toil; they are diligently sought . . . And until able women have given their lives to investigation, it is idle to discuss their capacity for original work." Mitchell, however, felt that there were some areas of research where women might particularly excel: specifically those requiring painstaking measurement and attention to detail.

THE ROLE OF WOMEN'S COLLEGES

Maria Mitchell saw the end of the era when astronomy was done by lone reasonably well-off amateurs. Advances in technology — photography, spectroscopy, larger telescopes — soon led to a rise in the number of observatories and a rise in the cost of doing astronomy. Formal education came to be a necessity, and learned societies began distinguishing the professional scientists from the self-taught amateurs. (And of course, women, being ipso facto amateurs, were therefore not welcome!)

As the end of the nineteenth century approached, the availability of higher education for women increased dramatically. At the fore in the U.S. were the women's colleges: in addition to Vassar, there were Mt. Holyoke (founded in 1837), Smith (1871), and Wellesley (1875), to name some of the earliest. Graduate education, a new-fangled idea of the men's universities, was still fairly hard to come by. Winnifred Edgerton, who graduated from Wellesley in 1883, fought long and hard to be allowed to attend Columbia University, where she earned the first Ph.D. in astronomy by an American woman in 1886; she was followed by four more women in the 1890s.

An education was of course no guarantee of a job. Dorothea Klumpke—who later set up an endowment at the A.S.P.—earned her doctorate and a position in Paris; Margaretta Palmer (Ph.D. 1894) stayed on as a computer at Yale. The women's colleges were a small exception: 16 women found work as professors and/or observatory directors at Vassar, Mt. Holyoke, Smith, Wellesley, and coed Swarthmore between 1865 and 1926. In some cases this resulted in a chain of women several generations long: at Vassar, Maria Mitchell was succeeded by Mary Whitney, one of her first students, who in turn was succeeded by Caroline Furness, Vassar class of 1891.

The research done at the women's colleges tended to be similar to Mitchell's early program at Vassar: patient, repetitive observation of objects such as comets, asteroids, variable stars. As Pamela Mack has noted, "The professors at the women's colleges chose research problems in the areas stereotyped as women's work because those topics could be pursued with the equipment they had available and because male astronomers they consulted about their research programs suggested those topics." The rigorousness of their course work does not seem to have been below the standards of the men's schools, though. The second student physics laboratory in the U.S., for instance, was established at Wellesley (where physics was required of all students!) in the late 1870s under Sarah F. Whiting, with advice from Edward C. Pickering who had recently designed the first such laboratory at MIT.

THE OBSERVATORIES

The new generation of college-educated women astronomers found some chances for employment as computers at the larger observatories. Vera Rubin relates a comment by one of her graduate students to the effect that the rapid rise of U.S. astronomy in the early 20th century was due to the fact that George Ellery Hale (builder of large telescopes) discovered money and Edward C. Pickering discovered women! Pamela Mack has found records of 164 women who worked for various U.S. observatories between 1875 and 1920. The Harvard College Observatory (HCO) hired its first women assistants in 1875. Pickering became director of the HCO two years later, and between then and his death in 1919 HCO employed 45 women, more than any other observatory. While Pickering encouraged bright young women to pursue higher education, he, along with most other scientific men of the time, believed that the intellectual abilities of women suited them for repetitive, non-creative data-gathering projects, not for original theoretical work.

Pickering was an early proponent of the growing science of astrophysics and a Baconian collector of data. He seems to have been supportive of women working in astronomy, but also highly economically motivated: in his 1898 annual report, he noted that women were "capable of doing as much good routine work as astronomers who would receive larger salaries. Three or four times as many assistants can thus be employed." The women at HCO usually received between 25 and 35 cents per hour. In a time of severely restricted opportunities, Pickering had applications from far more women than he could possibly employ. The women had no hope of advancing to positions where they might design independent research projects. Their tasks were of the type expected of women: many spent decades recording, cataloging, and classifying. In part because of the time spent and, hence, their extreme familiarity with their subjects, many produced extremely valuable work. (It was a reflection of the times that the group of women working at Harvard were nicknamed "Pickering's Harem.")

FLEMING AND CANNON

One of the first women hired by Pickering was Williamina Paton Fleming. Fleming was born in Scotland in 1857. She and her husband emigrated to the U.S. in 1875. When their marriage disintegrated two years later, leaving her pregnant, Fleming found employment as a maid with Pickering. By 1881 she was working at the observatory, initially doing fairly routine projects. With time her responsibilities increased. Studying photographic spectra, Fleming discovered 94 of the 107 Wolf-Rayet stars[3] known at the time of her death, 10 of the 28 known novae, 222 long-period variable stars; she edited observatory publications and became supervisor of the increasing number of women assistants. The bulk of the first Henry Draper catalogue of stellar spectral types was based on her classifications. (Henry Draper was a well-to-do New York physician and amateur astronomer; his widow donated a considerable amount of money to the Harvard observatory in his memory.) In 1898 Fleming was given a Harvard Corporation appointment as Curator of Astronomical Photographs, the first such appointment made to a woman. In 1906 she was elected an honorary member of England's Royal Astronomical Society. In addition to her career, she successfully raised her son Edward and put him through MIT. Fleming seems to have subscribed to the idea of a "woman's place" in the observatory: she spoke at the 1893 Chicago World's Fair on 'A Field for Women's Work in Astronomy', valuable despite its restrictions. Fleming died in 1911 at the age of 54.

Fleming was succeeded as Curator of Astronomical Photographs (although not by Corporation appointment) by Annie Jump Cannon, Wellesley class of 1884. Cannon was born in 1863 into a fairly well-to-do family; her mother was an amateur astronomer and sparked her interest in the sky. Studying at Wellesley under Whiting, Cannon developed an interest in spectroscopy. Following her graduation, Cannon dutifully spent a decade at home with her parents in Delaware, "very dissatisfied with life . . . [because there] are so many things that I could do." Cannon returned to Wellesley as a physics assistant following her mother's death in 1894. She took astronomy classes at Radcliffe and in 1896 joined the staff at HCO.

Cannon rearranged Fleming's spectral classification system to reflect systematic trends in the strengths of all spectral lines, not merely those of hydrogen. This meant dropping some of Fleming's letter classes and reordering others. The result is the OBAFGKM series of spectral types, reflecting decreasing stellar surface temperature, that is still (with minor modifications) in use today.[4] Following her appointment as Curator of the photographic collection, Cannon began a systematic classification of all stars on all Harvard photographic plates down to 9th magnitude. In all, she examined and classified nearly 500,000 spectra. In sparse regions, she could classify at a rate of better than three stars per minute, calling out her observations to an assistant. Her classifications were accurate to 1/10 of a spectral type (determined years later when Cannon reclassified a number of spectra). Her work was published as the nine-volume Henry Draper Catalogue between 1918 and 1924.

In recognition of her contributions to astronomy, Cannon received six honorary degrees, including one in 1925 from Oxford. She was elected to the RAS in 1914. In 1932 she received the Ellen Richards Research Prize, awarded by the Association to Aid Scientific Research by Women. This latter included a cash award which Cannon gave to the American Astronomical Society (AAS) to establish a regular prize for outstanding research by women astronomers. (The Cannon Award has been presented roughly every three years since 1934; since 1974 the Award has been made by the American Association of University Women with advice from the AAS.) Cannon regularly attended meetings of the AAS, serving as the Society's Treasurer for several years in the 1910s and as Councilor in the late 1930s.

Despite the value of her spectral classifications and the notice her work garnered elsewhere, Cannon received no official recognition from Harvard for decades. As early as 1911 a visiting committee report concluded that "It is an anomaly that, though she is recognized the world over as the greatest living expert in this line of work . . . she holds no official position in the university." It was 1938, three years before her death, before the Harvard University Corporation appointed Cannon, who was then 75 years old, a professor of astronomy.

MAURY AND LEAVITT

Cannon classified; her system was easy to use, her personality was charming, her work was performed at an incredible rate. Only the first of these is applicable to another of the members of "Pickering's Harem." Antonia C. Maury, a dour and talented astronomer whose physical insights and boredom with drudgery did not well fit her for the routine work of spectral classification. Maury was born in 1866, the niece of Henry Draper. After her graduation from Vassar in 1887, her father implored Pickering to give Maury a job. She worked, off-again and on-again, at HCO until 1935.

Where Cannon's early tasks had included classification of a sequence of southern stars, Maury was assigned plates of the northern sky. She, too, was dissatisfied with Fleming's scheme (some of which was simply in error due to the poor quality of the early photographs) and devised her own. In addition to the relative strengths of various lines, Maury's system took note of the sharpness of the lines. Since an entire photograph could be blurry owing to a poor-quality observation, this usually meant that a classification required the additional time spent examining a comparison plate. Pickering, who was proud of the efficiency of his computers, found this exasperating. Maury's classification of 681 stars was not ready for publication until 1897. Her classification scheme, with its 22 Roman-numeral types subscripted with three sharpness classes, was awkward to use. Her realization that there existed multiple classes of stars with the same spectral type contributed, though, to Ejnar Hertzsprung's recognition of the existence of the giant stars. He tried, in vain, to convince Pickering of the importance of Maury's sharpness criterion. In 1943 the AAS awarded Maury the Cannon prize for her work.

In addition to classification, Maury studied spectroscopic binaries—stars whose double nature is evident only through spectroscopic analysis. The first such double-lined star was discovered by Pickering and interpreted correctly, with Maury's help, as being due to two very close stars whose spectral lines shift as they orbit each other. Maury discovered the second-known spectroscopic binary, beta Aurigae, and spent considerable time studying an extremely close pair, beta Lyrae. As Cecilia Payne-Gaposchkin noted, Maury had a flair for identifying tough problems!

Perhaps the most brilliant of the early women astronomers at HCO was Henrietta Swan Leavitt, who came to the observatory as a volunteer in 1895. Leavitt, daughter of a Congregational minister, graduated from Radcliffe (or The Society for the Collegiate Instruction of Women, as it was known then) in 1892. Her work was interrupted for several years by an illness that left her hearing impaired. She returned to HCO on a permanent basis in 1902 at the age of 34.

At HCO, Leavitt worked on a north polar sequence of stars to be used as standards for photographic photometry; her results were used until the advent of photoelectric photometry in the 1940s. She also worked cataloging variable stars, identifying over 2000 to add to Harvard's collection. As with most things the computers did, this was a tedious process, involving overlaying two photographs taken at different times, one negative and one positive, and looking for stars whose images were different sizes on the two plates.

It was in studying variables in the Magellanic Clouds that Leavitt made her greatest discovery. The Magellanic Clouds are small companion galaxies to the Milky Way, visible from the southern hemisphere; since they are at a great distance from us, about 160,000 light years, all the stars in, say, the Small Magellanic Cloud (SMC) are at roughly equal distances from us. (The example is often used that to a person in New York, all people in Los Angeles are roughly the same distance away.) Since the stars are all at the same distance, differences in observed stellar brightness must reflect intrinsic stellar differences. Leavitt found 25 Cepheids (named for the prototype star of this type, delta Cephei) in the SMC, with periods between about 2 and 40 days, and discovered that the brighter the star, the longer its period of variability. Once the distance to the nearest Cepheids was found, this Period-Luminosity Relation, as it became known, meant that the intrinsic brightness of any Cepheid could be found from simple observations. From this and its apparent brightness, astronomers could then immediately "read off" the distance to the star - something that was quite difficult to find for any but the nearest stars.

The discovery of the Period-Luminosity Relation ultimately gave us our first means of measuring extragalactic distances and was used to demonstrate conclusively that many of the 'nebulae' known were actually galaxies in their own right. Leavitt, however, was not being paid to investigate the physical nature of variable stars nor to theorize about distances. The applications of her work were left to her male colleagues, while she returned to the drudgery of measuring plates. Unlike Maury, she does not seem to have complained about the work assigned to her. Still, it must have been frustrating, as Payne-Gaposchkin notes: ``It may have been a wise decision to assign the problems of photographic photometry to Miss Leavitt, the ablest of the many women who have played their part in the work of Harvard College Observatory. But it was also a harsh decision, which condemned a brilliant scientist to uncongenial work, and probably set back the study of variable stars for several decades.'' Leavitt's work did receive some attention: Professor Mittag-Leffler of the Swedish Academy of Sciences deemed her contributions to be of such value as to warrant nomination in 1925 for the Nobel Prize. Leavitt had unfortunately died four years previously, although only 51.

Cecilia Payne-Gaposchkin

When Cecilia Payne came to HCO in 1923, she inherited Henrietta Leavitt's desk. Over the next fifty years, Payne played a significant role not only in the burgeoning field of astrophysics but also in widening the opportunities available to women in astronomy.

Payne was born in England in 1900. She attended Newnham College, Cambridge, where she became interested in astronomy after hearing lectures by Sir Arthur Eddington. She graduated in 1923 and came to the U.S., seeking better prospects for advanced study and employment than were available to women in England. The new director of HCO, Harlow Shapley, was establishing a graduate program in astronomy and had no difficulty with women students. Payne was offered one of the Pickering Fellowships (established for study by women). In 1925 her Ph.D. dissertation, entitled Stellar Atmospheres, was published by the observatory. Her degree (awarded by Radcliffe rather than Harvard due to her sex) was the first astronomy doctorate earned at Harvard; it has been called, by the notable astronomer Otto Struve (as late as 1960!), "undoubtedly the most brilliant Ph.D. thesis ever written in astronomy."

For her dissertation, Payne took stellar spectra from the Harvard photographic collection and combined measurements of spectral lines with theoretical predictions of how temperature and ionization state in a star's atmosphere should affect the strength of the line (predictions published in 1920-1921 by Meghnad Saha) to obtain a temperature scale for Cannon's spectral types. Payne also determined that stars, contrary to current belief, were mostly composed of hydrogen and helium. In discussions with Henry Norris Russell, at Princeton, Payne became convinced that this was impossible and did not publish her conclusion; sadly, she received no credit for this discovery several years later when Russell reached, and published, the same conclusion.

Following her degree, Payne worked for HCO; this meant constraints since the subjects of her research were expected to correspond to the goals of the observatory, which did not have the advanced spectroscopic equipment Payne would have needed to pursue her dissertation work. The bulk of her scientific life was spent on the study of stellar magnitudes and distances, and, following her marriage in 1934 to Russian emigre astronomer Sergei Gaposchkin, on variable stars. Together, she and Sergei determined light curves for about 2000 variable stars down to 10th magnitude.

Payne-Gaposchkin was one of the first women to try to blend research and family. "While marriage was deemed an asset in male candidates for teaching and observatory positions, it was a detriment for women. Female computers and professors were expected to resign their posts if they married, the better to assist their husbands." Payne-Gaposchkin kept her position. (Payne-Gaposchkin further offended tradition by delivering a paper when five months pregnant with her first child; such behavior was vehemently vetoed in the future!)

Payne-Gaposchkin was by and large, as with the women before her, recognized but not adequately rewarded for her work. She was elected to the RAS before she graduated from Cambridge, won the (first) Cannon prize in 1934, was elected to the American Philosophical Society in 1936 and the American Academy of Arts and Sciences in 1943, and was awarded the AAS Henry Norris Russell prize for a lifetime of eminent astronomical research (although this recognition came only in 1976). Despite being one of the most accomplished astronomers of her time, Payne-Gaposchkin was never elected to the National Academy of Sciences (NAS), did not receive the A.S.P.'s Bruce Medal, was turned down for numerous possible appointments, and did not receive any official recognition from Harvard for decades. As she noted in 1930: ". . . I received absolutely no recognition, either official or private, from Harvard University or Radcliffe College; I cannot appear in the catalogues; I do give lectures, but they are not announced in the catalogue, and I am paid for (I believe) as `equipment'; certainly I have no official position such as instructor." In 1956, at the age of 56, Payne-Gaposchkin was appointed full professor and made chair of Harvard's astronomy department, the first woman to hold such a position not specifically designated for a woman. The appointment prompted the rather large Payne-Gaposchkin to note that she found herself in "the unlikely position of a thin wedge."

CONCLUSION

The 'wedges' have had some effect, albeit slowly. The American Astronomical Society (AAS) saw its first woman Vice President, Charlotte Moore Sitterly[5] in 1958. E. Margaret Burbidge (who has participated in seminal work on stellar nucleosynthesis, galaxy dynamics, and quasars) served as AAS President from 1976-78, and became the first woman to receive the Bruce Medal in 1982. Sidney C. Wolff (stellar activity and composition), currently head of the National Optical Astronomical Observatories, has recently been elected and will take office as the AAS's second woman president in 1992; she served as A.S.P. President in 1985 and 1986.[6] Graduate programs do not, at least overtly, discriminate against women (although Princeton University, a bit of a holdout, did not admit women to its graduate astronomy program until 1975). Colleges are less likely to deny women faculty timely promotion and tenure than in Payne-Gaposchkin's day. Observatories no longer object to women observers, although some did well into the 1960s (the living quarters on Mt. Wilson were dubbed 'The Monastery'; since there were no women's restrooms, women obviously could not be allowed to come to the mountain to observe!) Several women astronomers have been elected to the National Academy of Sciences (NAS), including Burbidge in 1978 and Vera Rubin (at the forefront of the quest for 'dark matter') in 1981. The list of prominent women astronomers is certainly longer than it was in 1950, when among a total community of about 300 there were about 50 women astronomers with Ph.D.s from U.S. institutions.

Still . . . The 11 female charter members of the AAS constituted about 10 percent of the society; that percentage, having risen somewhat and fallen somewhat over the years, stands now at about 11 percent, although the total number of women members is, of course, larger. Similarly, the percentage of women earning astronomy doctorates each year in the U.S. peaked at about 25 percent in the 1920s (and was about as high during WWII) and then fell to about 10 percent in the late 40s. Women professors still are paid, on average, about 93 percent of what their male peers receive. The 1976 Smithsonian exhibit on American astronomy not only didn't include Maria Mitchell, it didn't include any women.

Women's attitudes toward themselves have certainly changed over the past two centuries. Caroline Herschel wrote that "I did nothing for my brother but what a well-trained puppy dog would have done: that is to say, I did what he commanded me. I was a mere tool which he had the trouble of sharpening." Maria Mitchell, in defense of women in astronomy, wrote that "[o]bservations of this kind are peculiarly adapted to women . . . The eye that directs a needle in the delicate meshes of embroidery will equally well bisect a star with the spider web of the micrometer." Cecilia Payne-Gaposchkin, more on 'offense,' frequently advised young women contemplating a career in astronomy, "Do not undertake a scientific career in quest of fame or money . . . Undertake it only if nothing else will satisfy you, for nothing else is probably what you will receive." A significant number of young women seem to be taking that challenge: more than 20 percent of the AAS members under 30 are female.

FOOTNOTES:

1. A significant exception is former A.S.P President and the Director of the National Optical Astronomy Observatories Sidney Wolff. She is the co-author, with David Morrison and Andrew Fraknoi, of a series of textbooks, including those first begun years ago by the late George Abell. - Ed.

2. For more on the work of the women mentioned in this article, and many others, see the bibliography later in this issue. - Ed.

3. Wolf-Rayet stars are now known to be hot, bright, massive stars that are ejecting a shell of material; novae are stars that show a sudden outburst of radiation. - Ed.

4. It is a reflection of the mostly male makeup of astronomy professors that the mnemonic with which most students remembered these spectral types for decades was "Oh, Be A Fine Girl, Kiss Me." Today students can substitute "Guy" for "Girl," or, better yet, as urged by Owen Gingerich at Harvard, come up with new mnemonics such as "Oh Boy, An F Grade Kills Me!" or "Oh Brother, Astronomers Frequently Give Killer Midterms!" - Ed.

5. Sitterly, who won the A.S.P.'s Bruce Medal in 1990 - the year of her death - was known especially for her definitive work on atomic energy levels. See *Mercury*, Nov/Dec 1990, p.179. - Ed.

6. The A.S.P. elected its first woman president, Ann Boesgaard of the University of Hawaii, in 1977. Katherine Kron had served as the editor of the *Publications of the A.S.P.* from 1961 to 1967, the first woman to hold the editorship of a major astronomical journal. - Ed.

Courtesy Lowell Observatory

Percival Lowell

RESOURCES FOR EXPLORING THE WORK AND LIVES OF ASTRONOMERS

by Andrew Fraknoi
The Astronomical Society of the Pacific
390 Ashton Avenue
San Francisco, CA 94112

The materials below illustrate how astronomers in the 20th century do their work, the kinds of lives they lead, and the way their work and lives are intertwined. Readings marked with a • are especially useful for those just becoming familiar with the subject.

NOTE that there is a separate reading list about women astronomers in the this section of the notebook.

SELECTED READINGS FOR TEACHERS & ASTRONOMERS

READINGS ON 20TH CENTURY ASTRONOMERS IN GENERAL

Dressler, A. *Voyage to the Great Attractor.* 1994, Knopf. The story of the discovery of large-scale structure in the universe, with profiles of the astronomers involved, written by one of the participants.

• Goldsmith, D. *The Astronomers.* 1991, St. Martin's Press. This companion book to the PBS TV series, focuses on the work of a number of astronomers in frontier areas of research.

Lightman, A. & Brawer, R. *Origins: The Lives and Worlds of Modern Cosmologists.* 1990, Harvard U. Press. Interviews with the leading scientists who work on the large-scale properties of the universe. Some sections use technical terms freely, but there is a nice introduction to set the scene.

Overbye, D. *Lonely Hearts of the Cosmos.* 1991, Harper Collins. A well-written book about how cosmology is done today with profiles of astronomer Allan Sandage and other scientists.

• Preston, R. *First Light.* 1987, Atlantic Monthly Press. Eloquently written profile of the life and work of a number of astronomers who use the 200-inch telescope on Palomar Mountain.

Swift, D. *SETI Pioneers.* 1990, U. of Arizona Press. Interviews with the principal scientists and engineers involved in the scientific search for extra-terrestrial intelligence. Each person tells a bit about how they got interested in science and their present work.

Williams, T. "A Galaxy of Amateur Astronomers" in *Sky & Telescope*, Nov. 1988, p. 484.

READINGS ABOUT SELECTED 20TH CENTURY ASTRONOMERS

Bart Bok

Levy, D. *The Man Who Sold the Milky Way.* 1993, U. of Arizona Press. A biography written by an amateur astronomer about an astronomer who made major contributions to our understandings of the Milky Way Galaxy and of star formation.

Oort, J., et al. Special Issue of *Mercury* Magazine Devoted to Bart Bok. Mar/Apr. 1984.

White, R. "Bart J. Bok: A Personal Memoir from a 'Grandson'" in *Sky & Telescope*, Oct. 1983, p. 303.

S. Chandrasekhar

Tierney, J. "Quest for Order: Profile of S. Chandrasekhar" in *Science '82*, Sep. 1982, p. 68.

Wali, K. *Chandra: Biography of S. Chandrasekhar.* 1991, U. of Chicago. Biography of the Indian-born, Nobel-prize winning astrophysicist.

Frank Drake

• Drake, F. & Sobel, D. *Is Anyone Out There?* 1992, Delacorte Press. Autobiography of the astronomer who pioneered searching for radio messages from possible extraterrestrial civilizations.

Schechter, B. "Combing the Cosmic Haystack: Frank Drake" in *Discover*, Mar. 1983, p. 44.

Arthur Eddington

Douglas, A.V. *Arthur Stanley Eddington.* 1957, Thomas Nelson

MCrae, W. "Arthur Stanley Eddington" in *Scientific American*, June 1991, p. 92.

Tenn, J. "Arthur Stanley Eddington" in *Mercury*, Jul/Aug. 1993, p. 119.

Albert Einstein

Bernstein, J. *Einstein.* 1973, Viking.

Friedman, A. & Donley, C. *Einstein as Myth and Muse.* 1990, Cambridge U. Press.

Gribbin, J. & White, M. *Einstein: A Life in Science.* 1993, Simon & Schuster.

Highfield, R. & Carter, P. *The Private Lives of Albert Einstein.* 1994, St. Martin's Press.

• Hoffman, B. & Doukas, H. *Albert Einstein: Creator and Rebel.* 1972, New American Library.

Pais, A. *Subtle is the Lord: The Science and Life of Albert Einstein.* 1983, Oxford U. Press. Technical in many places.

Stephen Hawking

Boslaugh, J. *Stephen Hawking's Universe.* 1985, Morrow.

Boslaugh, J. "The Unfettered Mind: Stephen Hawking" in *Science '81,* Nov. 1981, p. 66.

• Ferguson, K. *Stephen Hawking: The Quest for a Theory of Everything.* 1991, Bantam Books. A clear profile of the British physicist and cosmologist, who has overcome the handicap of a terrible neuromuscular disease.

Hawking, S. *Black Holes and Baby Universes and Other Essays.* 1993, Bantam. Includes an autobiographical essay.

Hawking, S. & Stone, G., eds. *A Brief History of Time: Reader's Companion.* 1992, Bantam. Includes much biographical material on Hawking.

White, M. & Gribbin, J. *Stephen Hawking: A Life in Science.* 1992, Dutton.

Karl Henize

Robinson, L. "Conversation with Astronomer-Astronaut Karl Henize" in *Sky & Telescope,* Nov. 1986, p. 446. Astronomer Henize was the oldest man to fly in space.

Fred Hoyle

Hoyle, F. *Home is Where the Wind Blows.* 1994, University Science Books. An autobiography of the controversial astronomer who was one of the authors of the steady state universe and model, and helped explain how the stars make the elements.

Overbye, D. "Fred Hoyle: The Man Who Believes in Forever" in *Discover,* May 1981, p. 68.

Edwin Hubble

Jones, B. "The Legacy of Edwin Hubble" in *Astronomy,* Dec. 1989, p. 38.

Osterbrock, D., et al. "The Young Edwin Hubble" in *Mercury,* Jan/Feb. 1990, p. 2.

Osterbrock, D. "Edwin Hubble and the Expanding Universe" in *Scientific American,* July 1993, p. 84.

Sandage, A. "Inventing the Beginning" in *Science '84,* Nov. 1984, p. 111.

Sharov, A. & Novikov, I. *Edwin Hubble: The Discoverer of the Big Bang Universe.* 1993, Cambridge U. Press. Translated from the Russian.

Henry Norris Russell

DeVorkin, D. "Henry Norris Russell" in *Scientific American,* May 1989.

Tenn, J. "Henry Norris Russell" in *Mercury,* Sep/Oct. 1993, p. 19.

Carl Sagan

Bingham, R. "Interview with Carl Sagan" in *New Scientist,* Jan. 17, 1980, p. 152.

Cooper, H. *The Search for Life on Mars.* 1980, Holt Rinehart and Winston. Includes a long profile of Carl Sagan, that first appeared in *The New Yorker,* June 21 & 28, 1976.

Goodell, R. *The Visible Scientists.* 1977, Little Brown. Has a chapter on Sagan.

"The Cosmic Explainer" in *Time* magazine, Oct. 20, 1980, p. 62.

Allan Sandage

Overbye, D. *Lonely Hearts of the Cosmos.* 1991, Harper Collins.

Harlow Shapley

Bok, B. "Harlow Shapley: Cosmographer and Humanitarian" in *Sky & Telescope,* Dec. 1972, p. 354.

Gingerich, O. & Welther, B. "Harlow Shapley and the Cepheids" in *Sky & Telescope,* Dec. 1985, p. 540.

Mather, M. "Harlow Shapley, Man of the World" in *American Scholar,* vol. 40, p. 475 (1971).

Wright, F. "Harlow Shapley: A Tribute to a Great Man" in *Mercury,* Mar/Apr. 1973, p. 3.

Iosef Shklovsky

Goldberg, L. "Josif Shklovky: A Personal Memoir" in *Sky & Telescope,* Aug. 1985, p. 109.

Shklovsky, I. *Five Billion Vodka Bottles to the Moon.* 1991, Norton. Autobiographical sketches from the late Soviet astronomer, with a fascinating picture of Soviet science.

Gene & Carolyn Shoemaker

Levy, D. "Carolyn Shoemaker" in *Sky & Telescope,* June 1991, p. 658.

Preston, R. *First Light.* 1987, Atlantic Monthly Press. Has a section on the Shoemakers.

Reeves, R. "Interviews with Gene & Carolyn Shoemaker: Meteor Crater to Palomar" in *Astronomy,* June 1993, p. 13.

George Smoot

Smoot, G. & Davidson, K. *Wrinkles in Time.* 1993, William Morrow. Autobiographical book by the scientist who led the team that discovered the variations in the cosmic background radiation.

Clyde Tombaugh

Levy, D. *Clyde Tombaugh: The Discoverer of Pluto.* 1991, U. of Arizona Press.

Tombaugh, C. "The Discovery of Pluto" in *Mercury*, May/June 1986, p. 66 and Jul/Aug. 1966, p. 98.

Tombaugh, C. & Moore, P. *Out of the Darkness: The Planet Pluto.* 1980, Stackpole Books.

John Wheeler

Overbye, D. "John Wheeler: Messenger at the Gate of Time" in *Science '81*, June 1981, p. 60.

Overbye, D. "God's Turnstile: The Work of John Wheeler and Stephen Hawking" in *Mercury*, July/Aug. 1991, p. 98.

NOTE: Women astronomers are listed in a separate bibliography.

SELECTED READINGS FOR STUDENTS

Grades 4-6

Asimov, I. *Astronomy Today.* 1990, Gareth Stevens. An introduction to doing astronomy today, some of the instruments that are used, and a number of astronomers (including Percival Lowell, Einstein, and amateur Leslie Peltier).

DeBruin, J. *Scientists Around the World.* 1987, Good Apple Books. Somewhat superficial, but includes capsule biographies and some activities about several astronomers including Einstein, Carl Sagan, S. Chandrasekhar, etc.

Sprungmann, B. & David, L. "Spiraling Among the Stars: Interview with Vera Rubin" in *Odyssey*, Mar. 1994, p. 35.

Corliss, J. "Sallie Baliunas: Journeying to a Star" in *Odyssey*, Mar. 1994, p. 20.

"A Cosmic Conversation: Jill Tarter Talks about Listening for Life Elsewhere" in *Odyssey*, 1993, issue 7, p. 32.

Villard, R. "Interview with Allan Sandage" in *Odyssey*, 1992, issue 10, p. 21.

Levy, D. "Clyde Tombaugh: The Man Who Found Pluto" in *Odyssey*, 1992, issue 4, p. 14.

Barnes-Svarney, P. "To Study the Stars" in *Odyssey*, 1992, issue 2, p. 12. Profiles of astronomers Barbara Whitney, Andrea Dupree, and David Levy.

Grades 7-9

Cohen, D. *Carl Sagan: Superstar Scientist.* 1987, Dodd Mead.

Cwiklik, R. *Albert Einstein and the Theory of Relativity.* 1987, Barron's.

Simon, S. *Stephen Hawking: Unlocking the Universe.* 1991, Dillon Press.

SELECTED AUDIOVISUAL MATERIALS

The Astronomers (1992 video series, PBS Video) Six episodes of the PBS television series, focusing on exciting areas of modern astronomy and some of the astronomers who are doing the work.

Cosmos (1980 videos, Turner Home Video or the Astronomical Society of the Pacific) Thirteen episodes of the award-winning PBS series, in which Carl Sagan introduces his personal view of key astronomical ideas.

Women in Astronomy (1992 slide set, Astronomical Society of the Pacific) Slides and extensive background information on the contributions to astronomy by women and some of the challenges faced by today's women astronomers.

Astronomers of the Past (1986 slide set, Astronomical Society of the Pacific) 50 portraits of major figures in the history of astronomy, with a booklet of capsule biographies.

COMPUTERS & ASTRONOMY

If you haven't checked out the universe of astronomy available on computers, you don't know what you're missing.

Ten years ago few astronomical programs existed. By contrast, a dizzying collection of excellent ones exists today. If you're a potential buyer, you probably feel a little overwhelmed. This guide attempts to alleviate that by describing some of the programs available and explaining how to choose them. And because a computer is capable of doing much more than running a program, this guide also lists electronic bulletin boards that can be accessed (see "Electronic Connections") and CD-ROMs that can be purchased and used for data and image storage (see "Megastorage").

The heart of the computer universe lies in software that lets observers explore the richness of the night sky, plan and record observations, and enhance images. Though many of the programs speak to the needs of observers, armchair astronomers needn't feel left out. A growing number of programs animate celestial events or explore the nature of astronomical objects.

Observers can do many of the tasks that computers perform—making finder charts, plotting the position of a new comet, and entering notes about star clusters from an observing session. But who wants to spend hours redrawing charts by hand or computing the position of an asteroid using a calculator or a pencil and a piece of paper? Computers can save time—and drudgery—and let observers spend more time at the telescope. With a computer, you can control your telescope and observe from the comfort of your home.

But computers do more than save labor. They also present the universe in ways unimagined. Recently developed programs let users tour the Local Group of galaxies, watch solar and lunar eclipses, hike the surface of Mars, enhance images taken with film and CCD cameras, build binary star systems, and much more.

Selecting software involves many personal choices, so this guide can't say which programs are best for you. But to help you decide, it does indicate which programs are DOS-, Windows-, or Mac-based and which require special hardware such as a math coprocessor, a CD-ROM drive, or a particular display.

Astronomical software falls into several main categories: observing programs, image-processing programs, and special-purpose programs. **Observing programs** contain four subgroups: planetarium-type programs, sky simulators, deep-sky-observing programs, and observatory programs. (See "The Electronic Sky.")

Planetarium-type programs show the positions of the stars and planets and display constellation figures. Most of these programs will show deep-sky objects such as star clusters and galaxies. Some will also plot the positions of asteroids, comets, and the past and future positions of planets.

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Sky simulators don't plot constellation lines or coordinate grids as planetarium-type programs do, but they outdo these programs at showing how the sky really appears at night. They add twilight glow and other features to mimic the sky.

Deep-sky observing programs excel at showing the positions of numerous galaxies, nebulae, and star clusters. These programs also show the positions of stars, sometimes plotting fainter stars than planetarium-type programs. They also print finder charts for use at a telescope.

Observatory programs operate a telescope from a computer. In most cases the developers have combined a planetarium-type program with a telescope controller. So finding an object becomes as simple as moving a cursor to it on a sky map displayed on the monitor and clicking on a mouse to move the scope.

Image-processing programs enhance images with a variety of techniques that mimic what photographers perform in their darkrooms. (See "Image Processing.")

Special-purpose programs explore binary stars, plot the path of an eclipse, explore telescope optics, investigate the orbits of stars and planets, view Mars from its surface, make a planet, keep logs of observing sessions, and much, much more. (See "Expanding Your Horizons.")

THE ELECTRONIC SKY

Planetarium-type programs, sky simulators, deep-sky software, and observatory programs all open a window to the universe for personal computer users. These observing programs indicate the planets' positions each night, determine the phase of the Moon, locate deep-sky objects such as nebulae and galaxies, plan an observing session, or create a finder chart for use at the telescope. These programs work for armchair explorers as well by showing the position of a planet 1,000 years ago or helping determine its coordinates 1,000 years in the future. The programs also display the distribution of star clusters throughout the Galaxy, animate the motions of planets through the sky, and show the planets from different positions within the solar system. The one you choose depends on the observing you do or the phenomena you want to explore.

Choices were easier several years ago because few programs existed, especially for Windows-based or Macintosh computers. But now many fine programs are available for different types of computers and their various operating systems. Before purchasing a program, note if it requires a special video display, a math coprocessor, or an extraordinary amount of hard-disk space. Most Windows-based programs still work in 3.0 but a few require 3.1. A few Mac programs now require System 7.X. More and more programs offer CD-ROMs as an option for extending their database or for loading the program and database.

One factor in deciding between observing programs is the extent of their databases. Traditionally these programs have used the *Bright Star Catalog* to show the positions and brightnesses of over 9,100 stars brighter than about magnitude 6.5—or a portion of this catalog. Others used the 250,000 stars of the Smithsonian Astrophysical Observatory (SAO) star catalog, extending the brightness limit to 8th magnitude. Now many of the programs use the Hubble *Guide Star Catalog* with its over 15 million stars or provide this catalog as an option. In either case a CD-ROM drive is needed to use this catalog.

The position and brightness of galaxies, nebulae, and star clusters form a program's deep-sky object database. Some of the inexpensive programs use only Charles Messier's catalog of 110 objects. Most use part or all of the *New General Catalogue* that lists almost 8,000 objects. A few deep-sky observing programs add other catalogs to this basic database, including fainter nebulae, galaxies, and star clusters. With these extra catalogs, users can customize their observing database to concentrate on their interest in double stars, supernovae remnants, open star clusters, globular star clusters, or other types of objects.

While deep-sky programs have extensive databases, not of all of them display the planets —but planetarium-type programs will. So a planetarium-type program can still be a helpful tool for deep-sky observers, especially for finding the phase and location of the Moon. Some of these programs show the four largest satellites of Jupiter and a few also feature other planetary satellites. Many of the programs now add comets and asteroids to their database or permit the user to add elements that describe an object's orbit so the program calculates a comet's or asteroid's position for any time. This latter method is superior because the program can then determine the rapidly changing orbit of a comet such as Shoemaker-Levy 9, which collided with Jupiter in July 1994. Updated orbital elements for comets and asteroids are often available on astronomical bulletin boards or on-line computer services (see "Electronic Connections").

Some of the observing programs display images of the planets and some deep-sky objects or let users add personal digital images to the file. This feature appeals greatly to organizers of Astronomy Day programs, club events, school presentations, or anyone who needs a convenient means of keeping track of favorite astronomical photos.

To keep track of the skies as they were over 100 years ago or how they will be 100 years from now, chose a program that calculates precession, the slow wobble of Earth's axis over 26,000 years. Exploring ancient skies is one way to get a better feel for how our ancestors viewed the universe: It didn't always look the way it does today. Be warned that not all programs use orbital calculation methods that are precise enough to compute planetary positions far into the past or future, so check the program's accuracy.

Most programs can animate the motions of current solar system events such as the next solar eclipse or the path of an upcoming opposition. While the eclipse feature will show only the disappearance of the Sun as the Moon passes in front of it, another program is available that plots the path across Earth's surface (see "Expanding Your Horizons"). The animation feature can also find conjunctions (groupings of the planets in the sky) and possible occultations (events that occur when the Moon passes in front of a star).

Two more useful features to look for include the program's ability to print finder charts and to show the finderscope's or eyepiece's field of view. If the program can print finder charts, be sure that chart-printing routine works with the printer. Check that different classes of deep-sky objects are selectable to make customizing the chart easier. Some programs permit users to attach labels to objects on the chart or to keep observing notes for each object.

The other useful item displays a rectangle or circle on the screen showing the size a finderscope's or eyepiece's field of view. Some of these programs show the actual size of an object, not just a symbol in its position. And one program even shows the orientation of a galaxy in the sky.

Finally, those who own a computerized telescope can run it with a planetarium-type or observatory program. These programs are easy to use once loaded: simply select the desired object on the screen with the cursor, and a click of the mouse button will send the telescope on its way to the object. Many programs will control Meade's LX-200 series of telescopes and some will also control a CCD camera. For another telescope, check with the software developer to see if their program will work with that model.

PLANETARUIM-TYPE PROGRAMS

Program Name	Version	Developer	Price	Comp	System	CD-ROM	H. Drive	Mem	Display	# Stars	# Objects	Opt DB	Rev
Big Blue Skies		Andromeda Soft.	S	PC	DOS		—	—	VGA	1,500	—	3,200 stars	
Dance of the Planets	2.7	ARCSci. Sim.	$145	PC (286)	DOS		1.2 MB	640KB	VGA	9,100	1,400	yes	5/92
Dance of the Planets	Q.E.D.	ARC Sci. Sim.	$195	PC (286)	DOS		yes	640KB	VGA	9,100	1,400	yes	
Distant Suns	4.2	Virtual Reality	$199.95	Amiga			—	1MB	—	—	2,000	yes	
Distant Suns	2.0	Virtual Reality	$199.95	Mac	6 or 7		3.5MB	2MB	—	10,000	2,000		3/94
Distant Suns	2.0	Virtual Reality	$149.95	Mac	6 or 7	X	3.5MB	2MB	—	15 million	—		3/94
Distant Suns	2.0	Virtual Reality	$169.95	PC (386)	Win 3.1		5.5MB	2MB	VGA	9,100	450		4/92
Distant Suns	2.0	Virtual Reality	$149.95	PC (386)	Win 3.1	X	5.5MB	2MB	VGA	15 million	—		
Earth Centered Universe	1.5	Nova Astronomics	$135	PC (386)	Win		—	700KB	EGA	9,100	10,000	yes	
Expert Astronomer		Expert Software	$149.95	Mac	6.0.4		1.3MB	2MB	—	9,100	110		7/93
Expert Astronomer		Expert Software	$114.95	PC	DOS		no	512KB	CGA	9,100	110		12/92
Expert Astronomer		Expert Software	$114.95	PC	Win 3.1		yes	2MB	VGA	9,100	110		
Genesis	3.0	Lewis-Michaels Eng	$169.95	PC (286)	DOS		15MB	—	CGA	259,000	7,840	yes	
LodeStar	2.1	Zephyr Services	$189.95	PC	DOS		—	—	CGA	9,000	110		
LodeStar Plus II		Zephyr Services	$149.95	PC	DOS		no	—	CGA	9,100	7,840	260,000 stars	
LodeStar Pro	1.02	Zephyr Services	$259.95	PC (286)	DOS	optional	3 MB	2 MB	VGA	9,100	110	yes	10/94
MacStronomy	2.0	Etlon Software	$160	Mac	6.0.4		yes	2MB	—	9,100	1,100	yes	
NightSky		Zephyr Services	$179.95	PC	DOS		—	—	CGA	9,000	—	50,000 stars	
PC SKY	1.1	CapellaSoft	$199	PC (286)	DOS		3.2MB	640KB	VGA	178,000	200		8/93
PLAstro		Zephyr Services	$199.95	PC	DOS		2.5MB	—	VGA	9,100	—		
Redshift		Maris Multimedia	$199	Mac	7	X	1.5 MB	4 MB	color	200,000	40,000		9/94
Redshift		Maris Multimedia	$199	Power Mac		X	—	—	—	200,000	40,000		
Redshift		Maris Multimedia	$199	PC	Win 3.1	X	1.5 MB	4 MB	SVGA	200,000	40,000		9/94
Silicon Sky	6.2	Algol Software Works	$112	PC	DOS		—	—	EGA	—	—		
SkyGazer		Carina Software	$179.95	Mac			—	—	—	—	—		
Sky Globe	3.6	KlassM Software	$120	PC	DOS		no	640KB	CGA	29,000	110	yes	
StarGaze	2.1	C.E.B. Metasystems	$199.95	PC	DOS		6MB	640KB	EGA	500,000	9,000	yes	6/93
Superstar	4	picoScience	$149.95	PC	DOS		10MB	640KB	VGA	259,000	7,800	yes	
Superstar Pro	4	picoScience	$249.95	PC	DOS		10MB	640KB	VGA	259,000	7,800	yes	
The Cosmos	3.0	Mensys	$189.95	PC (386)	OS/2		4MB	—	VGA	9,100	150		
TheSky level II	2.0	Software Bisque	$129	PC	Win 3.1		5.5MB	1 MB	VGA	47,000	7,840		5&6/93
TheSky level III	2.0	Software Bisque	$199	PC	Win 3.1		12MB	1MB	VGA	259,000	13,000		
TheSky level II	5.0	Software Bisque	$199	PC	DOS		5.5MB	—	—	47,000	7,840		
TheSky level III	5.0	Software Bisque	$175	PC	DOS		12MB	—	—	259,000	13,000		
TheSky GSC	2.0	Software Bisque	$249	PC	Win 3.1	X	5MB	4MB	—	15 million	80,000		
Visible Universe	6	Parsec Software	—	PC	DOS		4MB	2MB	VGA	—	—	—	
Voyager II		Carina Software	$159.95	Mac	6 or 7	optional	1.5MB	2MB	—	50,000	4,200	yes	12/93
Voyager		Carina Software	$124.95	Amiga	—		—	1MB	—	9,100	1,200	yes	

DEEP-SKY PROGRAM

Program Name	Version	Developer	Price	Comp	System	CD-ROM	H. Drive	Mem	Display	# Stars	# Objects	Opt DB	Rev.
Arizona Database	8.0	Arizona Database	$189.95	PC	DOS		13.5MB	—	—	—	60,000		
Dark Sky	1.0	Arizona Database	$129.95	PC	Win		—	—	—	259,000	61,000		
Deep Space 3D	3.0	David Chandler	$179	PC	DOS		2.5MB	512KB	CGA	19,600	13,000	yes	4/93
Guide	2.0	Project Pluto	$169	PC	DOS	X	yes	640KB	EGA	15 million	38,000		8/94
HyperSky		Willmann-Bell	$149.95	PC	DOS	optional	2.3MB	500KB	CGA	46,000	5,500	yes	11/92
MegaStar	1.8	E.L.B. Software	$139	PC (286)	DOS	X	8-54MB	500KB	VGA	15 million	84,383		10/93
MegaStar		E.L.B. Software		PC (286)	Win	X	8-54MB		VGA	15 million	84,383		
NGP	2.5	Gary Williams	F	PC	DOS		2MB	512KB	VGA	—	8,164		1/92
Saguaro Database	6.0	Saguaro Astr. Club	$112	—	—		—	—	—	—	10,000		
SkyBase 2000.0	6.2	SkyBaseSoftware	$164.95	PC	DOS		2MB	512KB	CGA	45,000	13,000	yes	

OBSERVATORY PROGRAMS

								Mem	Display				Rev.
AstroSearch		Meade Instruments	$199.95	PC	Win 3.1		yes	640 KB	CGA				
Epoch 2000	1.04	Farpoint Research	$329	PC	Win		5MB	640KB	EGA	45,000	13,000		9/93
Personal Observatory		CompuScope	$399	PC	DOS				VGA	—	—		
Remote Observing	1.0	Software Bisque	$299	PC	Win 3.1		yes	—	VGA	—	—		
Sky Pilot		Carina Software	—	Mac	—	—	—	—	—	—	—		
Stars & Scopes		So. Stars Software	$149	Mac	6.0.8		1MB	2MB	—		8,000		

An "S" in the "Price" column indicates a shareware program; if you like the program and want to keep it, you pay the developer an amount specified in the program's documentation. An "F" indicates a freeware program; the developer provides this program to the community free. "Display" lists the minimum requirement. The program may support higher video modes. "Opt. DB" indicates whether optional databases are available to extend either the stellar or deep-sky databases. "Rev." indicates in which issue of ASTRONOMY a review of the software appeared.

No list of software can be complete since vendors introduce new software every day and multiple versions of some programs exist. No attempt was made to completely tabulate the multitude of shareware programs. We invite any software developer whose products are not contained in any of our tables to send a description of the software to Software Guide, ASTRONOMY Magazine, P.O. Box 1612, Waukesha, WI 53187. Review copies of programs are always appreciated.

IMAGE PROCESSING

Take an image, stretch its contrast, increase its brightness, and sharpen its blurry features: that's the genesis of an enhanced image. These same steps could have been performed in a darkroom, but how many astrophotographers have one in this era of one-hour photo processing? Besides, who wants to mix smelly chemicals, worry about the temperature of the developer, and enlarge and dodge many prints until the features of a celestial object come out just right? The digital darkroom is faster, cleaner, more powerful, and a lot more fun.

Most people think about CCD images when they hear the words "image processing," but actually the digital darkroom can enhance any image. Graphics houses (see "Color Separations" in the Yellow Pages) can scan negatives, prints, or slides with a special reader that converts photos into digital files. Or the local Kodak photo lab can convert the photos to digital images on a Photo CD (you need a CD-ROM drive to read these disks). And armchair astronomers who want to manipulate astronomical photos but don't want to take them themselves, can also obtain many images on CD-ROM (see "Megastorage").

Whatever the source, the fun begins with reading an image into the computer's memory and enhancing the faint features not normally captured with the eyes alone. A dozen-or-so programs are available to chose from, ranging in price from about $30 to $800. Price considerations should certainly drop the selection down to a handful. Options narrow from there for owners of IBM PC-compatible computers and become even more limited for the Macintosh and Windows environments. Many of the program developers use DOS to reduce the systems requirements on the computer's memory.

Ask developers what video display cards their image-processing software supports. Some support only specific cards because of the requirements of their programs. Others will support almost any VGA or Super VGA card.

Another factor to consider is image format. Not all programs support all of the different image formats such as FITS or the ST6 CCD camera format. And not all programs support color images or the combination (called compositing) of three separate images taken through colored filters into one tricolor image. But more and more of the programs now support tricolor compositing and others will add this feature soon.

Lots of inexpensive programs perform many tasks of image processing, such as calibrating the image using flat field and bias frames and plotting histograms to show the brightness range of an image. Image calibration is an important step because it removes differences in sensitivity between pixels (picture elements, or each element in a CCD array). This step is akin to developing film. Enhancement steps like brightness stretching and sharpening are similar to printing in the darkroom.

Inexpensive programs also provide many of the basic enhancement functions and filters. Filters are mathematical tools that act in predetermined ways on adjacent pixels. An example is the high-pass filter that suppresses large-scale variations in an image but maintains the small-scale (high frequency) details.

More expensive programs add additional features such as the ability to work on more than one image simultaneously and more powerful math functions, such as Fourier transforms or maximum entropy deconvolution. These latter functions remove the effects of bad seeing or poor guiding from the image. Several programs also work with 32-bit data, which unleashes the full power of an 80386- or 80486-based computer.

Some of the programs are now capable of running a CCD camera, eliminating the need for multiple programs to obtain and process images. All in all, this is probably the fastest-changing area of the astronomical software market. Developers will release several major upgrades and at least one new program by the time this guide reaches your hands.

IMAGE-PROCESSING PROGRAMS

Program Name	Version	Distributor	Price	Comp	Sys	Notes
AstroIP	1	Willmann-Bell	$129.95	PC	DOS	general image processing
CB245PIX		Richard Berry	$149.95	PC	DOS	image processing for TC245 Cookbook camera
Enhance		Owl Computer Serv.	$189	PC	DOS	general image processing
Hidden Image	1.3	Sehgal Corp.	$299	PC	DOS	maximum entropy deconvolution routine
Hidden Image 512	1.3	Sehgal Corp.	$399	PC	DOS	version for ST-6 cameras
Imagine-32	3.0	CompuScope	$299	PC	DOS	32-bit image processing
Imagine-32 Pro	3.0	CompuScope	$699	PC	DOS	version with extra filters and Fourier transforms
Improces	3.0	John Wagner	$125	PC	DOS	GIF and PCX image editor
Mira	2.06	Axiom Research	$595	PC	DOS	powerful 32-bit image processing
MultiPIX		Richard Berry	$139.95	PC	DOS	image compositing for TC211 cameras
PhotoShop	2.5	Adobe Systems	$895	MAC	6.0.7	image processing for publication
PhotoShop		Adobe Systems		PC	Win	general image processing
PhotoStyler	2.0	Aldus Corp.	$795	PC	Win	image processing for publication
Pixfix		Bruce Johnston	$ 29.95	PC	DOS	general image processing
SkyPro	1.1	Software Bisque	$199	PC	Win	general image processing

MEGASTORAGE

Accessing large databases has been a stumbling block for many programs until recently. Previously it took dozens of high-density diskettes to hold a stellar database such as the Hubble *Guide Star Catalog*—even large hard disks were overwhelmed with it.

But a more convenient storage medium now provides access to dozens of large databases and hundreds of images without ever putting a strain on hard drives or requiring a floppy shuffle ("Now Insert Diskette #52"). Compact disks can manage up to 700 MB of data within their thin, 12-centimeter diameter. Writing to the disk isn't possible—hence the name "compact disk, read-only memory" and its subsequent acronym (CD-ROM)—but it's probably just as well. If it were, users might accidentally erase or corrupt the database.

Most astronomers and personal computer owners haven't used CD-ROMs until recently because CD-ROM drives were expensive and few astronomy disks existed. But most of the major astronomy software vendors have started to offer programs and databases on CD-ROM and prices for CD-ROM drives continue to drop. In fact, many new home computer systems include a CD-ROM drive.

In addition to their vast storage capability, CD-ROMs are cheap. The Hubble *Guide Star Catalog* with its 19 million objects would cost hundreds of dollars if purchased as a series of books. It's available on CD-ROM for just $29.95. Obtaining prints of all the planetary images now available on CD-ROM would prove costly and difficult. And manipulating the printed images is nearly impossible compared to computer processing of digital images. Just be sure your program can read the data format (FITS, PDS, and ARN are the most common ones) for the CD-ROM.

The exciting part is that the disks listed below are just the beginning. Every day astronomers and software vendors are producing new disks. Users will soon wonder how they got along without them.

EXPANDING YOUR HORIZONS

Many astronomers think of planetarium-type programs when they think of astronomical computing. But a wealth of special-purpose programs exist that go beyond charting the stars, plotting asteroids, or animating planetary motions. Many of these special-purpose programs tap into other dynamics of astronomy, and some even explore the nature of the universe in ways no other program can.

CD-ROMS NOW AVAILABLE

Images	Distributed by	Price	Format	Description
Amazing Universe	Hopkins Technology	$179.95	—	101 images of planets and deep-sky objects
Voyage to the Planets — 1	Astronomical Research Network	$149.95	ARN	Jupiter, Saturn, Uranus
Voyage to the Planets — 2	Astronomical Research Network	$149.95	ARN	Neptune
Voyage to the Planets — 3	Astronomical Research Network	$149.95	ARN	Mars
Voyage to the Planets — 4	Astronomical Research Network	$149.95	ARN	Venus
Voyage to the Stars — 1	Astronomical Research Network	$149.95	ARN	galaxies
Voyage to the Stars — 2	Astronomical Research Network	$149.95	ARN	David Malin collection of deep-sky objects
Voyage to the Stars — 3	Astronomical Research Network	$149.95	ARN	IRAS infrared sky images
Voyage to the Stars — 4	Astronomical Research Network	$149.95	ARN	Rudy Schild collection of deep-sky objects
Comet Halley, Int'l. Halley Watch	National Space Science Data Center	$152	FITS, PDS and text	Halley Watch data on 23 disks
IRAS Sky Survey Atlas (ISSA)	National Space Science Data Center	$138	FITS	12.5° x 12.5° images on 4 disks
Pre-Magellan Venus data	National Space Science Data Center	$120	PDS	Radar and gravity data for inner planets on 1 disk
Magellan Venus data	National Space Science Data Center		PDS and VICAR2	Radar mosaic images on over 50 disks
Viking Orbiter images of Mars	National Space Science Data Center	$138	PDS	Images on 4 disks
Voyager Spacecraft to Uranus vols 1-3	National Space Science Data Center	$132	PDS	6,538 images on 3 disks
Voyager Spacecraft to Saturn vols 4-5	National Space Science Data Center	$126	PDS	4,000 images on 2 disks
Voyager Spacecraft to Jupiter vols 6-8	National Space Science Data Center	$132	PDS	6,000 images on 3 disks
Voyager Spacecraft to Neptune vols 9-12	National Space Science Data Center	$138	PDS	10,000 images on 4 disks
Joint Education Initiative - earth science	Robert Ridky, Univ. of Maryland	—	PDS	Halley Watch, Voyager, and other data on 3 disks
Space Science Sampler vols 1&2	Randal Davis, Univ. of Colorado	—	PDS	800 Uranus images from Voyager on 2 disks
Space and Astronomy	Walnut Creek CDROM	$139.95	—	1,000 images of Earth, the planets, and space
Catalogs				
Selected Astronomical Catalogs	National Space Science Data Center	$126	FITS and text	120 catalogs on 2 disks
Principal Galaxy Catalogue	Observatoire de Lyon	$190	—	Information about 73,000 galaxies
Hubble Guide Star Catalog	Astronomical Society of the Pacific	$129.95		Positions and magnitudes of over 15 million stars
Databases				
Flares in Hydrogen Alpha	National Geophysical Data Center	$111	text	Solar flare records dating back as far as 1938
Regions of Solar Activity	National Geophysical Data Center	$111	text	Calcium plage and sunspot group data — 1958 to 1991
Solar Radio Bursts	National Geophysical Data Center	$111	text	Solar radio emissions
Solar Variability Affecting Earth	National Geophysical Data Center	$111	text	Flares, spot numbers, and solar irradiance on 1 disk
Interactive Disk				
View from Earth	Warner New Media	$179.98	—	Describes Earth, Sun, and Moon with text and

Eclipse programs will plot the path of a solar eclipse across Earth's face or predict the time of a lunar or solar eclipse more accurately than some planetarium-type programs. The program indicates whether the eclipse will be partial, total, or annular (for solar eclipses) and the precise percentage of coverage, or magnitude, as seen from any given location. They also determine the limits of visibility of a lunar eclipse or the time of the next solar eclipse in a Saros cycle (the 18-year cycle of similar eclipses).

Orbital programs and gravitational simulators show the motions of two or more stars or galaxies as they move around each other. Both of these kinds of programs reveal what happens to a planet in a binary star system or to two binary star systems that collide. Some of these programs show how two galaxies collide, reproducing the appearance of some actual galaxy pairs such as the Antennae, the Mice, and polar ring galaxies. Or they follow the dynamics of a star system as it coalesces or diffuses into space.

While some special-purpose programs simulate motions, others maintain specialized information. To help observers interested in deep-sky objects, asteroids, and variable stars, these programs maintain and access detailed observing logs, determine the position of an object in a photograph, or track the brightness of a variable star. Brightness variations of eclipsing binary stars are complex, but these programs will show how the stars pass in front of each other and how spots might change the brightness of the star system. Other programs locate a multitude of asteroids and determine their brightnesses.

Several other programs offer relief to astrophotographers attempting to calculate exposure times for different types of objects. These programs can also tell how much sky a lens or telescope-eyepiece combination will cover. They even go so far as to help determine the eyepiece's field of view and which eyepiece will split a close double star.

Need to know when is it best to observe a planet? No problem. There are programs that will calculate a planet's rise and set times and the time it crosses the local meridian. They can also provide the longitude of a planet's central meridian, which is important to know when looking for certain features such as Jupiter's Great Red Spot or Martian volcanoes.

A program can determine the times when the Moon may occult, or pass in front of, a bright star as seen from a given location. Other programs can show observers the positions of the moons of Mars and Jupiter—and the times of possible eclipses and occultations by the planet—before going out to look for them. Knowing the time well in advance can eliminate wasting it later.

Calendars find the dates of the New Moon for planning deep-sky observing sessions or other phases for lunar observing. Other calendar programs translate between different calendrical systems, such as Gregorian, Julian, Chinese, Japanese, Hebrew, and Islamic, which is important for tracing celestial events recorded by ancient astronomers.

Want to build a planet? Software makes it easy to explore what happens to a planet if volcanos spew too much—or not enough—carbon dioxide into the atmosphere, or if plate tectonics make the continents drift faster than those on Earth. Such simulations demonstrate how life may have differed from its present form or how life might have developed on Mars.

To observe satellites, a multitude of programs will track the orbital paths of the space shuttle and other Earth satellites. These programs list when and where to look to see these objects as they race across the sky. Other programs access the images sent back to Earth by weather satellites, which some amateurs find useful for planning special observing sessions and others enjoy for their picturesque nature. Other space-related programs simulate a spacecraft mission such as Voyager's trip to Jupiter, Saturn, Uranus, and Neptune.

Planetarium-type programs show what the universe looks like from Earth. A few can move off Earth to view the night sky from another planet or a point within the solar system. But a special-purpose program explores the nature of the Local Group of galaxies and how it fits into the local structure of the universe. Another shows the Milky Way Galaxy neighborhood from the vantage point of any star in the region. See how the constellation patterns change as you move through space.

Learn how a telescope works with an optical ray-tracing program. These programs reveal how individual beams of light reflect or refract through a scope's optics. They also distinguish between the types of refracting and reflecting telescopes, including advanced apochromatic and catadioptric telescopes. Different color light rays or rays that pass through different parts of the optics disclose possible aberrations in a scope.

Other programs present the physics of stars and how they emit light or study the intricacies of Einstein's theory of special relativity.

And if all this isn't enough to provide many evenings of enjoyment, various programs include an astronomical encyclopedia that can teach observers about the objects in the night sky. Or for a break from the thoughtful side of astronomy, relax with astronomically oriented games.

If you haven't done so already, put away that planetarium-type program for a while and let these special-purpose programs strut their stuff.

OTHER ASTRONOMY SOFTWARE

Program Name	Developer	Price	Comp	System	H. Drive	Mem	Display	Description
Asteroid Pro	**Pickering Anomalies**	**$169.95**	**PC (386)**	**DOS**	**40MB**	**3MB**	**color**	**Predicts occultations of stars by asteroids**
AstroCalc	Zephyr Services	$130-$200	PC	DOS	no	—	CGA-EGA	Gives planetary positions, rise and set times
Astronomy Lab	Pers. MicroCosms	$115	PC (286)	Win 3.1	1MB	1MB	—	Predicts astronomical phenomena
Astronomy Workbench	Io Solutions	$125	PC	DOS	—	—	EGA	Displays the night sky and simulates orbits
AstroPhoto	Zephyr Services	$129.95	PC	DOS	no	—	—	Calculates exposure times
AstroPix	F.C. Meichsner Co	$139.95	PC	DOS	no	—	—	Computes exposure times for astrophotos
AstroPlanck	Zephyr Services	$129.95	PC	DOS	no	—	VGA	Demonstrates how stars radiate energy
AstroPoint IV	Dale Ferguson	$129.95	PC	DOS	no	—	CGA	Calculates positions of objects in the sky
AstroSheet	C.E.B. Metasystems	$299.95	PC	Win	—	—	—	Uses Microsoft's Excel for calculations
Astro-3D	Zephyr Services	$130-$40	PC	DOS	no	—	CGA-EGA	Travels through the Sun's neighborhood
Beam 2	Stellar Software	$189	PC	DOS	no	—	—	Traces light through optical systems
Beam 2	Stellar Software	$189	Mac	—	—	—	—	Traces light through optical systems
Binary Maker	Contact Software	$159.95	PC	DOS	no	640KB	VGA	Simulates binary star orbits and brightnesses
Canon of Eclipses	Willmann-Bell	$129.95	PC	DOS	no	640KB	CGA	Displays lunar eclipses, from 1500 b.c.-3000 a.d
Ceres	Zephyr Services	$159.95	PC	DOS	7MB	—	EGA	Plots paths for over 5,000 asteroids
CircumSpace	KlassM Software	S	PC	DOS	no	640KB	EGA	Travels through the Sun's neighborhood
Dark Sky Calendar	Steve Voss	$124.50	PC	DOS	no	—	—	Prints monthly calendar with Moon phases
Discover Space	Brøderbund	$159.95	PC	DOS	—	—	—	Tours the solar system
Eclipse Live	Andrew Lowe	$139.95	PC	DOS	—	—	—	Displays solar eclipses accurately
EclipseMaster	Zephyr Services	$130-$50	PC	DOS	no	—	—	Computes solar and lunar eclipses precisely
Electronic PictureBooks	Astr. Soc. Pacific	$110-$40	Mac	7.X	yes	2.5MB	—	Contains images of planets and other objects
GalaxCrash	Zephyr Services	$130-$50	PC	DOS	no	—	CGA-EGA	Simulates collision of two galaxies
Galileo's Four	Zephyr Services	$129.95	PC	DOS	no	—	CGA	Shows positions of Jupiter's largest moons
Gauss and Laplace	Andromeda Software	S	PC	DOS	no	—	—	Computes orbit from three observations
Gravitator	Zephyr Services	$140-$150	PC	DOS	no	—	CGA-EGA	Computes orbits of stars and planets
Howington Orrery	Zephyr Services	$139.95	PC	DOS	no	—	CGA	Displays orbits in our solar system
JMoons	Andromeda Software	S	PC	DOS	no	—	EGA	Shows positions of Jupiter's largest moons
Jovian Traveler	Zephyr Services	$149.95	PC	DOS	no	—	CGA	Simulates spacecraft mission to Jupiter
Learn About Orbits	Andromeda Software	S	PC	DOS	no	—	EGA	Teaches concepts of orbital motion
MarsEGA	Andromeda Software	S	PC	DOS	no	—	EGA	Locates moons of Mars
Mars Explorer	Virtual Reality	$169.95	PC (386)	DOS	no	4MB	VGA	Maps Mars' surface; need CD-ROM drive
MICA	NTIS	$155	Mac	6.0.2	2MB	1MB	—	Computes precise planetary positions
MICA	NTIS	$155	PC	DOS	2MB	512KB	—	Computes precise planetary positions
MoonTracker	Zephyr Services	$130-$40	PC	DOS	no	—	CGA-EGA	Displays lunar eclipses and visibility
Optics Lab	Sci. Lab Software	$179	PC (386)	Win. 3.1	644KB	—	—	Traces light through optical systems
Orbits	Soft. Marketing Corp.	$159.95	PC	DOS	no	512KB	EGA	Provides information about the solar system
Orbits	Phy. Acad. Software	$159.95	PC	DOS	no	384KB	CGA	Simulates orbits of stars and planets
Our CosmoHood	Bondono Software	$125	PC	DOS	600KB	—	EGA	Shows our Local Group of galaxies
PC GOES/WEFAX	Soft. Systems Cons.	$250	PC	DOS	no	640KB	CGA	Captures weather satellite images
PC-Track	Andromeda Software	S	PC	DOS	no	—	EGA	Tracks Earth satellites
PEEP	C.E.B. Metasystems	$139.95	PC	DOS	yes	640KB	EGA	Finds eclipses, conjunctions, occultations
Personal Observing Log	Ohio Star Software	$120	PC	Win	no	—	—	Records your observing notes
Planets III	Aladdin Software	$139.95	PC	Win	3MB	2MB	—	Shows pictures of and describes the planets
Planet Tracker	David Chandler	$150	PC	DOS	no	512KB	EGA	Investigate the laws of planetary motion
Plate	Zephyr Services	$149.95	PC	DOS	no	—	—	Determines position of object in photo
Satellite Pro	Zephyr Services	$149.95	PC	DOS	yes	—	EGA	Calculates highly accurate satellite orbits
Satellite Tracker	Intellimation	—	Mac	6.0.5	yes	1MB	—	Tracks Earth satellites
Scope	Waldee-Wood	$149.95	PC	DOS	no	384KB	CGA	Calculates performance of telescope
Silicon Universe	Algol Software Works	$112	PC	DOS	no	—	—	Shows deep-sky objects outside our Galaxy
SimEarth	Maxis	$169.95	Mac	—	—	1MB	—	Creates a planet that then evolves
SimEarth	Maxis	$169.95	PC	DOS	—	640KB	EGA	Creates a planet that then evolves
SkyClock	Bodhi Software	$179.99	PC	DOS	no	512KB	—	Provides rise and set times for planets
Solar	Andromeda Software	S	PC	DOS	no	—	CGA	Displays solar eclipses from 1951 to 2032
SolarSpace	Zephyr Services	$139.95	PC	DOS	no	—	EGA	Shows Sun's neighborhood in 3D
SolarSys	Zephyr Services	$129.95	PC	DOS	no	—	VGA	Surveys the contents of the solar system
Space Adventure	Knowledge Adventure	$159.95	PC	DOS	7MB	—	VGA	Provides a tour of the universe
Spacetime	Phy. Acad. Software	$159.95	Mac	—	—	—	—	Explores the laws of special relativity

continued on next page

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OTHER ASTRONOMY SOFTWARE

continued from previous page

Program Name	Developer	Price	Comp	System	H. Drive	Mem	Display	Description
Spacetime	Phy. Acad. Software	$159.95	PC	DOS	no	—	—	Explores the laws of special relativity
StarBase	Altair Engineering	$199	PC	Win	—	—	—	Stores your observations, images, and text
StarCrossed	Zephyr Services	$129.95	PC	DOS	no	—	VGA	Introduces variable stars
STS-Orbit	Andromeda Software	S	PC	DOS	no	—	CGA	Displays shuttle orbital paths
SunTracker	Zephyr Services	$130-$130	PC	DOS	—	—	CGA-EGA	Displays solar eclipses and paths
TideMaster	Zephyr Services	$139.95	PC	DOS	no	—	—	Calculates times of high and low tides
TimeChecker	Zephyr Services	$139.95	PC	DOS	no	—	—	Gets correct time from U.S. Naval Obs.
Total Eclipse	Zephyr Services	$129.95	PC	DOS	yes	—	EGA	Displays solar and lunar eclipses
TrakSat	Zephyr Services	$189.95	PC	DOS	no	—	CGA	Follows Earth satellites in their orbits
VarBase	Zephyr Services	$129.95	PC	DOS	no	—	CGA	Records and displays variable star data
Vista Pro	Virtual Reality	$129.95	Mac	DOS	4MB	4MB	color	Creates Martian landscapes from Viking data
Vista Pro	Virtual Reality	$129.95	PC	Win and DOS	4MB	4MB	VGA	Creates Martian landscapes from Viking data
Where in Space	Brøderbund	$179.95	PC (386)	DOS	8MB	640KB	VGA	Presents a game set in the solar system
WinTrak	WinTrak	$149.95	PC(286)	Win	3MB	2MB	VGA	Tracks Earth satellites

An "S" in the "Price" column indicates that the program is shareware. If you like the program and wish to keep it, you must register your copy with the developer and pay the fee listed with the program documents. "Display" lists the minimum display required. The program may support higher video modes.

FOR MORE INFORMATION, CONTACT:

Adobe Systems Inc., 1585 Charleston Road, Mountain View, CA 94039-7900, (800) 833-6687

Aladdin Software, 1001 Colfax Street, Danville, IL 61832, (217) 443-4611

Aldus Corp., 411 First Avenue South, Seattle, WA 98104-2871, (206) 628-2320

Algol Software Works, P.O. Box 6714, Orange, CA 92613

Altair Engineering, P.O. Box 301, Loma Linda, CA 92354, (800) 984-4545

Andromeda Software, Inc., P.O. Box 605, Amherst, NY 14226-0605, fax (716) 691-6731

ARC Science Simulations, Box 1955A, Loveland, CO 80539, (303) 667-1168, fax (303) 667-1105

Arizona Database Project, 3131 E. Thunderbird Road #8, Suite 130, Phoenix, AZ 85032, (602) 992-2813

Astronomical Research Network, 206 Bellwood Avenue, Maplewood, MN 55117, (612) 488-5178, fax (612) 487-3074

Astronomical Society of the Pacific, 390 Ashton Avenue, San Francisco, CA 94112, (415) 337-2624, fax (415) 337-5205

Axiom Research, Inc., 1304 East Eighth Street, Tucson, AZ 85719, (602) 791-2864

Richard Berry, 22614 N. Santiam Highway, Lyons, OR 97358

Bodhi Software, 2371 N. 64th Street, Wauwatosa, WI 53213, (414) 453-4123

Bondono Software, 51054 Kingwood, Shelby Township, MI 48316, (313) 731-4706

Brøderbund, P.O. Box 6121, Novato, CA 94948-6121, (415) 382-4400, fax (415) 382-4582

CapellaSoft, P.O. Box 3964, La Mesa, CA 91944, (800) 827-8265

Carina Software, 830 Williams Street, San Leandro, CA 94577, (510) 352-7328, fax (510) 352-2343

C.E.B. Metasystems, Inc., 1200 Lawrence Drive, Suite 175, Newbury Park, CA 91320, (800) 232-7830, fax (805) 498-5987

David Chandler, P.O. Box 309, La Verne, CA 91750, (714) 988-5678

CompuScope, 3463 State Street, Suite 431, Santa Barbara, CA 93105, (805) 687-1914

Contact Software, 725 Stanbridge Street, Norristown, PA 19401-5505, (215) 279-1940

Cosmo-Logique, P.O. Box 105, 398 Pilon, Dorion-Vaudreuil QU, J7V 5W1, Canada

Randal Davis, LASP, Campus Box 392, University of Colorado, Boulder, CO 80309

E.L.B. Software, 8910 Willow Meadow, Houston, TX, 77071, (713) 541-9723

Etlon Software, 1936 Quail Circle, Louisville, CO 80027, (303) 665-3444

Expert Software, P.O. Box 144506, Coral Gables, FL 33114-4506, (800) 759-2562

Farpoint Research, 10932 Hasty Avenue, Downey, CA 90241-4026, (310) 861-6606, fax (310) 862-1546

Dale Ferguson, 22341 Sprague Road, Strongsville, OH 44136

Hopkins Technology, 421 Hazel Lane, Hopkins, MN 55343-7116, (612) 931-9376

Intellimation, P.O. Box 1922, Santa Barbara, CA 93116-1922, (805) 968-2291

Io Solutions Limited, 19 Parklawn Avenue, Epsom, Surrey, KT18 7 SQ, England, phone: 0372-741439

Bruce Johnston Computing, 7764 Tull Court, Waterford, MI 48327, (810) 666-2186

KlassM Software, 284 142nd Avenue, Caledonia, MI 49316, (800) 968-4994 (orders only)

Knowledge Adventure, (800) 542-4240

Lewis-Michaels Engineering, 48 Delemere Blvd., Fairport, NY 14450, (716) 425-3470

Andrew Lowe, 4939 Vantage Crescent N.W., Calgary, AB, T3A 1X6, Canada

Maris Multimedia, 99 Mansell Street, London, E1 8AX, England, (800) 336-0185

Maxis, 2 Theatre Square, Orinda, CA 94563-3346, (800) 556-2947, fax (510) 253-3736

F. C. Meichsner, 182 Lincoln Street, Boston, MA 02111, (800) 321-8439

Mensys, P.O. Box 674, 2100 AR Heemstede, The Netherlands

National Geographic Data Center, Code E/GC2, Dept. 920, 325 Broadway, Boulder, CO 80303-3328, (303) 497-6761

National Space Science Data Center, Code 933.4, Goddard Space Flight Center, Greenbelt, MD 20771, (301) 286-6695

National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, (703) 487-4650

Nova Astronomics, P.O. Box 31013, Halifax, NS B3K 5T9, Canada, (902) 443-5989

Ohio Star Software, 8919 Deep Forest Lane, Centerville, OH 45458

Owl Computer Services, 5950 Keystone Drive, Bath, PA 18014, (800) 245-6228

Parsec Software, 1949 Blair Loop Road, Danville, VA 24541, (804) 822-1179

Personal MicroCosms, 8547 E. Arapahoe Road, Suite J-147, Greenwood Village, CO 80112, (303) 753-3268

Physics Academic Software, TASL, Box 8202, North Carolina State University, Raleigh, NC, 27695-8202, (800) 955-8275, fax (919) 515-2682

picoScience, 41512 Chadbourne Drive, Fremont, CA 94539, (510) 498-1095

Pickering Anomlies, P.O. Box 1214, Belmont, CA 94002, (415) 593-7332

Project Pluto, Ridge Road, Box 1607, Bowdoinham, ME, 04008, (207) 666-5750

Robert Ridky, Geology Department, University of Maryland, College Park, MD 20742

Saguaro Astronomy Club Database, A.J. Crayon, 13819 N. 37th Avenue, Phoenix, AZ 85023

Sehgal Corp., 1776 Windflower Way, Gloucester, ON, K1C 5Y9, Canada, (613) 794-1134, fax (613) 837-3011

Science Lab Software, 93 Albemarle Road, Norwood, MA 02062, (617) 769-5153

Signal Analytics, 440 Maple Avenue East, Suite 201, Vienna, VA 22180, (703) 281-3277, fax (703) 281-2509

SkyBase Software, 450 Spring Hill Drive, Morgan Hill, CA 95037

Software Systems Consulting, 615 W. El Camino Real, San Clemente, CA92672, (714) 498-5784

Software Bisque, 912 12th Street, Suite A, Golden, CO 80401, (303) 278-4478, fax (303) 278-0045

Software Marketing Corporation, 9831 South 51st

Street, Building C-113, Phoenix, AZ 85044, (602) 893-2400, fax (602) 893-2042

Southern Stars Software, 12525 Saratoga Creek Drive, Saratoga, CA 95070, (408) 973-1016

Stellar Software, P.O. Box 10183, Berkeley, CA 94709, (510) 845-8405, fax (510) 845-2139

Virtual Reality Laboratories, Inc., 2341 Ganador Court, San Luis Obispo, CA 93401, (805) 545-8515

Steve Voss, 595 Carina Drive, Lompoc, CA 93436

John Wagner, 6161 El Cajon Boulevard, Suite B-246, San Diego, CA 92115

Waldee-Wood Astronomical Software, 1468 Kimberly Drive, San Jose, CA 95118, (408) 723-3655

Walnut Creek CDROM, 1547 Palos Verdes Mall, Suite 260, Walnut Creek, CA 94596, (800) 786-9907, fax (510) 674-0821

Warner New Media, (800) 843-9497

Gary Williams, 11 Red Doe Cove, Cabot, AR 72023

Willmann-Bell, Inc., P.O. Box 35025, Richmond, VA 23235, (804) 320-7016, fax (804) 272-5920

WinTrak, 111 Emerald Drive, Harvest, AL 35749-9213, (205) 837-0084

Zephyr Services, 1900 Murray Ave., Pittsburgh, PA 15217, (800) 533-6666, fax (412) 422-9930

A GALAXY OF ASTRONOMY AND SPACE SOFTWARE

by Cary Sneider and Harald Berndt

Recently, the maverick President of Stanford University, Gerhard Casper, remarked that, in his view, large lecture halls will soon be replaced by technology that allows students to take courses while sitting at workstations and communicating with other students via computer screens. To prepare our students for such a life on campus, as well as for the world of computerized factories and offices, we need the best tools available—tools that allow students to become excited about science, to explore new worlds on their own, to learn how to learn. And where better to begin than at the furthest reaches of the known universe?

In this article we review some of the latest software in astronomy and space science for the IBM and Mac platforms. What we hoped to find were programs that allowed teachers to take advantage of the most recent capabilities of new computers—increased speed and storage capacity, excellent color graphics, as well as photos and videos that can now be brought to your classroom via CD-ROM players. We also looked at how those elements were put together from a teacher's perspective: Was the program easy and fun to use? Did it provide students with a structured approach through games or missions?

We also looked at each program from the viewpoint of what students learn. We wanted to know if the program offered opportunities for the students to learn more than trivial facts and figures. Did the software enable students to see how astronomers view the universe? Did students have a chance to review actual data and draw conclusions? Did the software help students get through typical stumbling blocks such as understanding the relationship between the backyard view of the sky and the space viewpoint of astronomical phenomena? Were students invited to think about the space program, and get involved in their learning, rather than just be told about it passively, as in a lecture hall?

Enough for expectations. How did the software pan out? It seemed to fall naturally into three categories: *multimedia libraries*, *tutorials and games*, and *software tools*. The categories are not iron-clad. For example, one of the multimedia programs contains a game that allows students to review what they learned; and some of the software tools make use of multimedia databases. Nonetheless, the categories are useful in seeing some of the major differences between the various kinds of programs that are now available.

Let's take a brief look at each one on its own terms, keeping in mind that the order in which we list them does not imply any judgments about which programs are best. We point out strengths and weaknesses, but leave it up to you to determine which will best serve your students and be compatible with both your hardware and your personal philosophy of teaching.

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MULTIMEDIA LIBRARIES

Want to send your students to the library to look up some facts on our nation's space missions or the planets? Send them to the computer instead with these database programs that store lovely images and video clips on astronomy and space science. However, keep in mind that you will probably have to design your own challenges and lesson plans to provide some structure to motivate and guide your students through these rich collections of information.

Americans In Space (Multicom Publishing, Inc.) Your students will quickly learn to use the mouse to navigate through this database of information with pages of facts, slides, and short QuickTime movies. We started by browsing through the "guided tours." By clicking on the Autopilot and Zoom commands we enjoyed the selection of images from the first flights to the Moon, right up to recent Space Shuttle missions and disasters.

Technically, the program is adequate. It's easy to navigate and graphics are colorful. On the other hand, a pause between each slide makes the slide show seem jerky, and the backgrounds and constructed images are simple and unimaginative. As with all QuickTime movies on CD's, the video clips are available on a small 2"x 2" screen. You can run them forwards, backwards, or in slow motion or stop-frame.

The information provided is selective, so before assigning a research project, try out the program yourself to be sure the information is there. You may also want to think up some interesting missions as a rationale for students to search the database, as these are not provided by the software or documentation.

Space Shuttle (The Software Toolworks) also provides information on the U.S. Space Program, with slide shows and video from NASA. To get started, students can select Astronaut Training School, where they may choose to view one of several short, narrated slide shows, including: orientation, training on flight profiles, astronaut's gear, or living and working in space. When you select a mission you can look at the crew dossier, "launch" the mission, or view mission highlights; but not actually participate in a mission as suggested in the advertising. Submenus for missions provide information screens, video clips, or narrated slide shows.

Technically, the software is excellent. It is entertaining and attractive, like the best one would expect from interactive television. The graphics and layout are very clear, utilizing photos of the interior of the Shuttle and Mission Control for realism. The narrated slide shows move seamlessly from slide to slide, so it is more like a video than still photos. The background music suffers from interruptions when the software loads new modules or screens.

"Lift-off" is an electronic version of a board game in which you must answer questions about the information learned previously to advance your game piece. A countdown severely limits the amount of time to answer the questions, making it extremely difficult to win. With such a technically well-executed program, we were disappointed that the test was a game of trivia rather than a series of missions requiring students to synthesize their knowledge and put it to work to solve problems.

Murmurs of Earth (Warner New Media, Time Life Books) is a database of all of the images and sounds sent along on the Voyager spacecraft, carrying information about our planet to some extraterrestrial civilization that might stumble upon it in the far distant future. From greetings in 55 languages, to mathematical equations and images of people and animals all over the world, this CD will bring these lovely images and sounds into your classroom. The disk normally comes with a book by the same title, but the book was not sent with our review disk, so we cannot comment on it here. The software allows you to step through each frame, one at a time, or to go to any frame in the list that comes with the CD.

Many of your students are likely to be fascinated by these beautiful sounds and images; but you will have to bring educational value to the program by how you introduce and use it. For example, you might ask your students to discuss what sounds and images they would send into space to communicate their personal perceptions of the Earth, or to write about what alien beings might think of Earth if they viewed the images on this disk.

Solar System (National Geographic Society) is a wonderful presentation tool for use by a teacher with virtually any Macintosh, laser disk player, and television monitor. Setup was very easy, once we had assembled all the equipment listed in the users guide. The combination of software and images on the disk offers visual and audio assistance in presenting concepts, as well as facts and images.

Solar System consists of four parts: a collection of *video chapters and resources,* which are photo essays and articles from the National Geographics Society archives; a *presenter* for putting together individualized sequences of the audio-visual material, and a *glossary.* The video chapters are scripted very clearly, and present spectacular astronomical photos and short videos. Each chapter includes *preview* questions that help to focus the students' attention, and *review* questions to help the students synthesize what they learned. The videos feature not just white males; but women astronomers too. Since the data is stored on a laser videodisk rather than CD-ROM, the software provides full-size, high quality videos.

The *presenter* allows the teacher to put together a script from pictures and short videos. When preparing your scripts, you select items from a complete inventory of all the photographs and videos on the disk, listed categorically by Solar System object. We created a presentation about Pluto in just a few minutes. The program also has the capability of printing questions for use in class discussions. Technically and educationally this package of laser disk and computer software came very close to meeting our expectations for a good multimedia library resource.

Beyond Earth (Optical Data Corporation) is one of three videodisks on astronomy and space science that are available in *The Living Textbook* series. Each disk contains thousands of full color, still images, and nearly a hundred short video segments. The company has come a long way since it pioneered the use of videodisks in the classroom more than a decade ago. In response to the need for a complete directory of what is on the disk, the package now includes a 166-page *Image Directory* which lists all of the images on the disk, and even provides transcripts of all narrations contained on the short video segments. But what about the time required to key in all the frame numbers? No problem. Next to each item in the *Directory* is a barcode. By connecting a barcode reader to the videodisk player, the teacher (or student) can immediately retrieve that image from the disk.

Still, flipping through pages from one barcode to the next takes time, so the package contains *Video Cards 3.0*—a HyperCard application that allows you to connect a Macintosh to the videodisk player and view prepared Tours, or create your own presentations. Each card in the stack represents a still image or video segment. As you prepare each card the program retrieves data on the image and allows you to make your own notes. A print capability allow you to list data, notes, and a set of barcodes (using a barcode font) so you can make a seamless presentation. *Video Cards 3.0* can be used with any laser videodisk. An additional HyperCard Stack called *Lesson Plans* makes it even easier to browse images and assemble a lesson. With regard to both technical capabilities and educational management tools, *Beyond Earth* is the most complete multimedia package that we have seen.

MULTIMEDIA LIBRARIES

Title	Publisher	Hardware	Est. Grade level	Subjects	Multimedia elements
Americans in Space	Multicom Publishing, Inc., 1100 Olive Way, Suite 1250, Seattle, WA 98101 (800) 850-7272	MPC-capable PC compatibleMacintosh with CD-ROM, HyperCard 2.0 or higher, System 7.0 or higher, and QuickTime 1.5 (supplied)	5-9	American space missions: facts, pictures, movies	Images, narration, movies
Space Shuttle	The Software Toolworks, 60 Leveroni Court, Novato, CA 94949 (800) 283-8499	Macintosh II series, LC series, or Quadra, 13" RGB color monitor (LC requres 512 kB of video RAM), Apple CD-ROM drive or compatible (150 kB/second transfer rate), hard drive, System 6.0.7 or higher, 4 MB RAM (2.5 MB free)	5-9	The Space Shuttle program: facts, pictures. movies, narration (on astronaut training)	Images, narration, movies
Murmurs of Earth, the Voyager Interstellar Record	Time Warner Interactive Group, 3500 Olive Avenue, Burbank, CA 91505 (800) 482-3766	IBM 286 compatible (requires Super VGA card for 640x480, 256 colors; Multisync monitor; PC-compatible CD-ROM drive; 640 kB available memory) Macintosh II-series or LC (requires 12- or 13-inch color monitor; System 6.0.5 or greater Macintosh-compatible CD-ROM drive; 2 MB available memory)	7-12	The Voyager interstellar record	Music, narration, images, text and symbols
STV Solar System	National Geographic Society, Washington, D.C. 20036 (800) 368-2728	Macintosh with at least 2 MB RAM, System 6.0.5 or higher, or at least 2.5 MB RAM and System 7.0 or higher, 3.5" disk drive, Hypercard 2.0v2 or higher, videodisk player, TV or video monitor and appropriate audio and video cables, RS-232 interface cable, printer (optional)	6-12	The solar system, formation of stars and planets, what astronomers do, space exploration	Narrration, images, movies
Beyond Earth: Astronomy, Sides 1 and 2	Optical Data Corporation, 30 Technology Drive, Warren, NJ 07059 (800) 524-2481	Macintosh with at least 2 MB RAM, System 6.0.5 or higher, or at least 4 MB RAM and System 7.0 or higher, 3.5" disk drive, Hypercard 2.1 included, videodisk player, TV or video monitor and appropriate audio and video cables, RS-232 interface cable, printer (optional) IBM 386SX-25 MHz compatible or better with 4MB of RAM; DOS 3.1; Microsoft Windows 3.1; VGA display 640x480, videodisk player, TV or video monitor and appropriate audio and video cables, RS-232 interface cable, printer (optional)	9-12	The solar system, formation of stars and planets, deep space objects, observatories	Music, narration, images, movies

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GAMES & TUTORIALS

Several of the software programs that we reviewed were set up to teach about astronomy and space science through games, illustrated lectures, and on-line activities. While you can certainly devise lesson plans to introduce students to the programs and assign special challenges, it is not essential that you do so. The logic of the game or tutorial already on disk will lead your students through a learning sequence.

Learn About the Night Sky (Wings for Learning) is a very simple interactive program designed for young children, allowing them to explore planets, stars, light, and space voyages through interactive games. The educational goal of this software is for students to learn facts. The method is for the students to click on clues and make guesses. The graphics are very crude. Moving around in the program is not difficult once you figure out what you are supposed to be doing and how to drag icons around the screen. Most students will probably be able to figure out the games with a little help. The "Create" mode is a paint program that invites the students to make simple astronomy-related pictures quickly and easily.

The disk comes with journals in the style of coloring books in which students draw their impressions. Since the astronomical objects are only represented with crude graphics, however, (no actual photographs are included), their drawings are not likely to be very informative. Despite its weaknesses, this program fills a gap at the younger age levels, and our limited tests show that children very much enjoy the interaction that the program provides.

Space Adventure (Knowledge Adventure Inc.) invites young children to explore space, time, and much of science, interactively. The program presents you with the *main screen*, a *text box*, a *time line*, *world view*, and a tool bar with *category buttons* and *function buttons*. The main screen shows the pictures and (six) movies that make up the main part of Space Adventure. You can point to sections of the pictures and find hints for further exploration. For example, a picture of the surface of Venus may allow you to click on a volcano to learn more about volcanoes. The following picture lets you click on a lava flow to learn more about lava.

All pictorial elements are acccompanied by well-written textual information, displayed in the *text box*. While many children may not read these, that's okay. They'll have a good time with the pictures and the text will be of value to their teachers and parents. The *time line* shows your position in the history of the Universe, and the *world view* gives you an idea of the spatial scale of objects. A complete index allows you to look up specific topics, but only by scrolling through a list of entries. There is no search feature. The *function buttons* include a retrace feature, which allows you to explore alternative paths through the available information.

Sometimes, clicking on the options to "learn more" will get you into a loop of repeating information. On the other hand, it is nearly impossible to exactly repeat a sequence of steps. There are four simulations of varying quality, but all are interactive and invite you to play. The large amount of information available, coupled with the easy-to-use interface and the ever-changing flow of the story, will keep kids of all ages adventuring for hours.

Where In Space is Carmen San Diego? (Brøderbund Software, Inc.) is a detective game, like its predecessors—Where In The U.S.A....? Where in the World...? Where in Time is Carmen SanDiego? The game allows you to pit your detective's wits against arch-criminals from throughout the galaxy. Traveling from one planet or moon to another, you query witnesses, listen to messages from the stars, or check a database of information on the Solar System. If you've learned enough about your quarry to obtain a warrant and find the right location, you're awarded with a promotion. The graphics are wonderful and the game element kept us playing all evening. However, it was important to discover that if we ended up on the wrong

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planet, the clues were meaningless, and we had to retrace our steps to get back on course.

In this iteration of the *Carmen* theme, your students are provided with a database containing all the answers to the clues. However, they must be willing to wade through several pages of on-screen text to track down clues like "Which body of the solar system has a crater named Con?" or to use a database search function which is very slow, even on a high-performance computer. Like the earlier *Carmen* games, this one allows students to gain factual information about the Solar System. But if you place a higher value on fundamental concepts and the methods of science, you'll want to continue your journey to another part of our galaxy.

The program comes with a Teacher's Guide and a small book entitled *Peterson First Guides: Astronomy*, by Jay Pasachoff. The field guide will help you find constellations in the sky, and learn more facts about the planets, but it is not very helpful in playing the game. In the Teacher's Guide, the first activity helps you instruct your students in the use of puns and word play to decipher the clues. Many of the other activities are fairly good hands-on activities, but they do not relate directly to the computer game nor do they form a coherent unit of study.

Orbits: Voyage Through the Solar System (Software Marketing Corporation) is an old favorite, included with this set of new software because it is still one of the best pieces of commercially available educational software in astronomy. The main menu takes you to the Earth, Sun, Moon, Planets, or General Astronomy areas. Within each area you can learn facts and figures by comparing the objects side-by-side. Short-term animations allow you to view such celestial events as eclipses and the fusion of subatomic particles within the sun. Most fun and interactive, however, are the several different games in the Orbit-Trek program, found under the General menu. The various scenarios start you off with a successfully orbiting satellite, and permit you to fire thrusters to change orbits, or rendezvous with another satellite.

The graphics are excellent and the interface is very easy to use. Although *Orbits* provides much of the same information as many other programs we reviewed, it is educationally better than most since students are led to make comparisons between objects, and to learn about satellite orbits thorough an interactive simulation game.

The View From Earth (Warner New Media, Time Life Books) is an audio visual textbook that provides some initial instruction in how to use the disk, and then a menu of choices of what the viewer would like to learn about. Once you choose your selection, however, there are no demands on you other than paying attention to the nicely narrated slide shows. Interactive elements include an Eclipse Tracker and a Library. The Eclipse Tracker allows you to click on the date of a solar eclipse from the past or future, and see locations in the world where best viewing would occur. The Library is an on-line encyclopedia that provides reading information and occasional photo essays. The documentation is very brief, and the program is very easy to use. The graphics and writing are lovely, but opportunities for user interaction are limited. Students who have difficulty reading may appreciate the spoken narration; but it is still necessary for students to pay attention to the illustrated lectures, and reading is needed to use the library entries.

Buzz Aldrin's Race Into Space (Interplay Productions, Inc.) is a strategy game simulation game of the U.S.-Soviet space race. You can become the Director of the U.S. or the Soviet space program and match your wits against the computer or a friend. As Program Director you visit the administration building to purchase equipment from the complete arsenals of either nation. You proceed to the Research and Development facility to spend money on technological improvements. You again visit administration to assign future missions, assign those missions in Mission Control and, after launch, follow the progress of your program by watching some actual video footage. Your brave deeds will be reported in the news at the beginning of the next season, when each player takes their next turn. You may check the Pentagon for intelligence reports, and visit the Capitol to examine your prestige points. But be warned of the wrath of the Vice President if your missions fail!

This game promises lots of fun for fans of strategic simulations. As in other such games, you will have to learn how the program evaluates your strategy, which may not be identical to an actual winning R&D strategy. The connection of this game to astronomy is tenuous, but the cross-curriculum connection between science and social studies is a wonderful way to show students how school subjects merge in the real world.

Star Probe (Artemis) is a very attractive simulation tool that makes the topic of stellar evolution into a real investigation for high-school students. The software invites you to select your research mission—to send probes to various stars or a nebula, where you can launch probes to take a closer look, to view the star in the past or future, or to observe its spectrum at any stage of evolution. All of the tools are easy to use and will require very little explicit instruction—even spectral analysis. By selecting stars of different masses, and watching their evolution forwards and backwards in time, students will soon be able to envision the entire lifetime of stars like our Sun, as well as discover where such exotica as black holes and supernovae come from.

Students should enjoy the freedom to explore and make discoveries using the Star Probe software, and teachers will enjoy the clearly focused educational objectives. The short selection of activities that come in the manual will help you create a meaningful unit of both on-line and off-line activities on the related topics of stellar evolution and spectral analysis. This one is clearly for the high school teacher who values concepts and investigation skills over facts and figures.

GAMES AND TUTORIALS

Title	Publisher	Hardware	Est. Grade level	Subjects	Multimedia elements
Learn About the Night Sky	SUNBURST/WINGS for Learning, 101 Castleton Street, Pleasantville, NY 10570 (800) 321-7511	Macintosh family, at least 2 MB, Color Mac required. Apple IIe, IIc, IIGS (128K), color monitor required, mouse and printer recommended	2-5	Planets, stars, comets, meteors, moons, constellations	Color graphics
Space Adventure	Knowledge Adventure, Inc., 4502 Dyer St., La Crescenta, CA 91214 (800) 542-4240	Macintosh family, at least 1 MB RAM, Color or gray-scale monitor, System 6.0.7 or higher, hard disk with at least 8-10 MB available, printer optional	4-8	Space missions, planets, geologic features, astronauts	Color graphics, text, videos, slides, simulation games
Where in Space is Carmen Sandiego?	Brøderbund Software, Inc., 500 Redwood Blvd., Novato, CA, 94948-6121 (800) 521-6263 (800) 482-3766	IBM compatible, 16 MHz 386 or faster, 640 kB RAM and hard disk with 8 MB free space, DOS 3.1 or higher, VGA monitor and card, mouse, keyboard, 1.44 MB 3.5" disk drive (color monitor; System 6.0.5 or greater, Macintosh-compatible CD-ROM drive; 2 MB available memory)	5-9	Solar system: names, pictures, facts, features; famous astronomers; mythology	Color graphics and images, sounds

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GAMES AND TUTORIALS

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Title	Publisher	Hardware	Est. Grade level	Subjects	Multimedia elements
Orbits: Voyage Through the Solar System	Software Marketing Corporation, 9831 South 51st Street, Suite C-113, Phoenix, AZ 85044	IBM PC, PS/1 or PS/2, 512K, MS-DOS 2.0 or above, EGA or VGA color graphics. 5.25" or 3.5" disk drive. Optional use of Microsoft Mouse, version 6.10 and above.	5-9	Solar system: names, pictures, facts, features; satellite orbits	Color graphics and images
The View from Earth	Time Warner Interactive Group, 3500 Olive Avenue, Burbank, CA 91505 (800)482-3766	Macintosh with CD-ROM player. System 6.0.7 or later. System 7 users need at least 4 MB RAM, but 5 is better. Requires color capability (intended for 256 colors)	7-12	Earth, Sun, moon, solar eclipses: facts, images, The Voyager interstellar record	Narration, music, color graphics and images
Buzz Aldrin's Race Into Space	Interplay Productions, Inc. Irvine, CA 92704 (800) 969-GAME	IBM and compatibles with 640K RAM, 3.5" HD disk drive, DOS 3.1 or higher, hard disk, VGA/MCGA required.	6-12	History of the space race	Sound, color graphics and images
Star Probe: A Tool Kit for Stellar Astronomy	Artemis Science Curriculum and Software, 3211 NE 50th Street, Portland,	Macintosh with 2 MB RAM and system 6.0 or later, 7.5 MB free memory on hard disk, 3.5" disk drive. Color required.	9-12	Evolution of stars, spectral analysis	Color graphics

SOFTWARE TOOLS

In the third category are software packages that allow students and teachers to use computers much as scientists do—as tools to answer questions, explore new terrain, and display large amounts of raw data so that it can be interpreted by people.

Voyager II (Carina software) "What phase was the Moon when the Declaration of Independence was signed in 1776?" "Will Venus be visible in the sky when I propose to my sweetheart next weekend?" For years our planetarium staff responded to questions like these by calling up Voyager on the office Macintosh. One of the most versatile interactive desktop planetariums, Voyager has now been replaced with the expanded Voyager II. The essential function of the program is to show you the sky at any time in the past, present or future, from any location on Earth. You can select any of several views: Star Atlas Local Horizon, Solar System, or the Milky Way View, each with the appropriate coordinate system. Then, set the control to show how the sky changes over time, zoom in or out, and click on any of thousands of stars, nebulae, or galaxies to learn about them

Voyager II is ideal for an amateur astronomer who wants to find certain objects to view, or a teacher who wants to select the best time of year to have her students observe the planets or schedule a star observing session. However, keep in mind that the manual starts with a primer on celestial coordinate systems, so it is probably not the best introduction to astronomy for young children.

Expert Astronomer (Expert Software) is also an interactive planetarium on the computer, with capabilities similar to Voyager II. Controls for selecting your location in space and field of view are handled very nicely and intuitively with the Mouse. We were also pleased with the sky light feature that shows whether the sky is light or dark as the program steps through time, showing you how the sky changes over the time increments that you selected. Color and graphics were acceptable, but not as good as in many other programs that do the same things.

Distant Suns 2.0 (Virtual Reality Laboratories, Inc.) is an especially attractive interactive planetarium program. The absolutely lovely graphics on a high-resolution monitor, ease of operation, wide array of capabilities, and good documentation make this software a delight to play with. As with other such programs, it helps to have a basic understanding of such topics as coordinates and Messier objects in order to use it as a tool. However, a teacher with some background in astronomy can introduce students to its capabilities one at a time. An especially attractive feature is the beautiful animation of the Solar System and the path of Halley's Comet, and the ability to zoom in and out, observe the Solar System from different positions, and at different points in time, and to animate the dance of the celestial spheres. The intrepid explorer will also find data on large asteroids, meteor showers, magnitudes and spectral classes of stars, galaxies and nebulae, star clusters, and even the path of the hobbled Galileo spacecraft.

Redshift (Maris Multimedia Ltd.) is the Ferrari of planetarium programs. It gives you spectacular performance; but also like a Ferrari, the controls are not as simple as your average Honda. Starting with the guided tours to learn the capabilities of the software, you will soon be able to display the sky from anyplace on the Earth, Mars, or the Moon, and search for objects visible by the eye or telescope, and center on them. You can use the "Filters" to display the planets, deep sky objects (galaxies, nebulae, and star clusters), asteroids, or stars that are of a certain brightness, or temperature range. You can also observe as a planet orbits the sun, noting how the planet's tilt causes the seasons. The photo gallery has some spectacular photos and montages of the solar system and deep space objects.

This is a serious tool for advanced students and hobbyists, or even professional astronomers. With its great pictures, movies, and guided tours, just playing with it is a rewarding experience. With RedShift, teachers truly have a planetarium on their desktop, and a fancy one at that. It is fairly easy to create your own movies of solar eclipses, rotation of planets and moons, and other time-varying phenomena.

Discover Space (Brøderbund Software, Inc.), for IBM and Tandy computers, has the same capabilities as most other planetarium-type programs, with the addition of a few animations. What is most significant for teachers, however, is that it is the only such program that includes a *Teacher's Guide*. The *Guide* contains advice on using just one or a classroom of computers, cooperative learning, a short list of resources for teaching astronomy, and some very good activities. For example, students are introduced to the software by answering the question: What did people who observed a UFO on January 25, from a certain location, actually see? Later, they use the software to predict the positions of constellations, planets, and a lunar eclipse, then go outdoors at night to find these objects and record their observations in a diary.

Amazing Universe (Astronomical Research Network and Hopkins Technology) shows how professional astronomers use image processing as a tool to discover more information than is accessible to the human eye. You have access to a library of 101 images on CD-ROM, taken by spacecraft and Earth-based telescopes, and you are given a professional-quality image-analysis program to manipulate them in various ways.

ProVision, the included image-processing program, offers various filters like "sharpen" and "smooth," a variety of false-color palettes, edge emphasizing, outlining and other fancy manipulations. While the images included in "Amazing Universe" are a bit less spectacular than those offered by other entries in this roundup, ProVision allows teachers and students to experiment with a state-of-the-art tool for sqeezing the last bit of information out of astronomical images.

Mars Explorer (Virtual Reality Laboratories, Inc.) is a database of Mars surface features for the IBM PC which provides opportunities for your students to explore the wonderful pictures of the entire surface of the red planet taken by the NASA Viking Orbiters. Students can start by watching as the sphere of Mars slowly rotates below them. They can then go to the map of Mars, and the Control Panel. With the use of arrow keys, they scroll their cursor around on the surface until they find the feature they wish to view. Selecting the level of zoom, they then view the actual pictures, realistically tinted with appropriate shades of red, white, and black.

Technically, this is good bare-bones database. It represents one of the ways that astronomers use computers—to organize information so it can be displayed quickly and easily. It takes just a few minutes to learn how to use the Control Panel. However, the interface leaves room for improvement. It would be good if the student did not have to go back to the control panel each time they wish to zoom in or out, add or delete labels, or turn the grid on or off. And, the educational value of the software would be greatly enhanced if the authors had considered including some slides of similar features on Earth taken from orbit at the same scale, to help students interpret these interesting features.

The program also has the capability to find a named feature. As with many of the programs we have looked at, this is a simple tool that requires a knowledgeable teacher. For example, a teacher might use a use a good book such as *The Surface of Mars* by Michael Carr (Yale University Press), to learn about the various features, then challenge the students with questions, such as: "Find a feature called Ceraunius Tholus (an obvious volcano). Can you explain the long channel that runs from the center to the edge? (It's a channel that leads from the caldera, down the slope into an impact crater.)"

Vistapro (Virtual Reality Laboratories, Inc.) is a three-dimensional landscape simulation program which utilizes actual data from US Geological Surveys and NASA spacecraft. Start by selecting a map of the region you want to explore. For example, it might be best to begin with Earth landscapes, such as Yosemite Valley or the San Francisco Bay Area. Within each map, select a data square. Specify where you want to place your "camera" and where you want to point it, and in about 60 seconds, the program will draw a picture of what you would see from that point of view. Unlike photos, buildings and birds are absent from these pictures which are based on the topology of the data base, but you can ask the program to add special effects such as clouds and trees, or change the snow or sea level, and see how it would look. Or, use a paint program to add details if you wish. Then, when your students explore the surface of Mars, they will understand what the program will be doing, and the approximate scale of the features they are looking at.

While not the simplest of programs, in a short time you can figure out how to get the different databases loaded into the computer, and how to select a point of view and render your first few pictures. The program rewards exploration. You could spend quite a lot of time on one map, and look at it from different viewpoints, or with different physical conditions. Or, you could go from map to map, sampling vastly different terrain. The demos provided with the program show what it can do with animations. The "bungie jump" is quite spectacular. The program invites you to create your own animated guided tour from point to point on the surface of Mars.

The great value of this program is to see how scientists use computers to explore another planet from data collected by spacecraft. It is best if you have a classroom full of IBM computers, so that students have time to make their own choices as they explore in groups of two or three. If that is not possible, you can awe your students with prepared slideshows and "fly-bys."

SOFTWARE TOOLS

Title	Publisher	Hardware	Est. Grade level	Subjects	Multimedia elements
Voyager II	Carina Software, 830 Williams St., San Leandro, CA 94577 (510) 352-7328	Macintosh with at least 1 MB free RAM, hard disk, and system 6.0.5 to 7.x. Large monitors and data extensions need 1.5 to 2.5 MB free RAM. Color recommended. Printer optional.	9-12	Desktop planetarium, solar system, constellations, asteroids, comets, deep space objects	Color graphics
Expert Astronomer	Expert Software, P.O. Box 144506, Coral Gables, FL 33114-4506 (800) 759-2562	Macintosh with at least 2 MB RAM, hard disk, and 3.5" disk drive, System 6.0.5 or better, printer optional.	9-12	Desktop planetarium, solar system, constellations, asteroids, comets, deep space objects	Color graphics
Distant Suns 2.0	Virtual Reality Laboratories, Inc., 2341 Ganador Court, San Luis Obispo, CA 93401 (805) 545-8515	Macintosh with at least 2 MB RAM, hard disk, and 3.5" disk drive. Recommended Macintosh II series, 68020 or better processor, math co-processor, printer optional.	9-12	Desktop planetarium, solar system, constellations, asteroids, comets, deep space objects	Color graphics, images, movies
RedShift	Maris Multimedia Ltd, 99 Mansell Street, London E1 8AX, ENGLAND	Macintosh LC II running System 7 or above, 4 MB RAM, CD-ROM, 1.5 MB hard disk space, color monitor, QuickTime 1.5 or above (supplied), printer optional	9-12	Desktop planetarium, solar system, constellations, asteroids, comets, deep space objects,	Color graphics, images, movies
Discover Space: School Edition	Brøderbund Software, Inc., 500 Redwood Blvd., Novato, CA, 94948-6121 (800) 521-6263	IBM/Tandy with 640K, 16 MHz 386SX or faster required, MS-DOS or PC-DOS 3.1 or higher, Sound Card and Mouse Recommended, VGA (color) and SVGA, 1.44MB 3.5" drive, Hard Disk with 7MB required	6-12	Desktop planetarium, solar system, constellations, asteroids, comets, deep space objects	Color graphics, images
Mars Explorer	Virtual Reality Laboratories, Inc., 2341 Ganador Court, San Luis Obispo, CA 93401 (805) 545-8515	IBM 386 or 486 with 4 MB RAM, VGA, Super VGA recommended. Microsoft compatible mouse and driver, CD-ROM Reader.	6-12	Mars, maps and map coordinates	Color graphics, images

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Software Tools

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Title	Publisher	Hardware	Est. Grade level	Subjects	Multimedia elements
Amazing Universe	Hopkins Technology, 421 Hazel Land, Hopkins, MN 55343-7116 (612) 931-9376	Macintosh II with 2 MB RAM, CD-ROM drive, System 7 compatible, color monitor and hard drive preferred. IBM PC or compatible with 640K, CD-ROM drive, Dos 3.1, 3.3 or higher, VGA or SVGA required, color monitor, hard drive, and mouse preferred, most SVGA cards supported, VESA compatible	9-12	Image processing of solar system and deep space images	Color graphics, images
Vistapro	Virtual Reality Laboratories, Inc., 2341 Ganador Court, San Luis Obispo, CA 93401 (805) 545-8515	IBM 386 or greater with at least 4 MB RAM, VGA, or SVGA (VESA Compatible). DOS 3.0 or better, Microsoft compatible mouse and driver, optional hard disk requires 3-7 MB.	7-12	Earth and Mars surface features, mapping terrain	Color graphics

Conclusions

We're happy to report that many software companies have moved agressively to put some of the most exciting images of astronomy and space science onto digital media for use in the classroom. In our opinion, companies that will be most likely to please teachers and students are those that have provided easy-to-use software to access those images, as well as games, missions, or powerful software tools that lead students to explore the wonderful worlds beyond the atmosphere of our planet. By getting students to use computers in order to discover what is "out there," we will be taking an important step in helping them learn how to use technology to take them where they want to go.

About the Authors

Cary Sneider *is Director of Astronomy and Physics Education at the Lawrence Hall of Science, University of California at Berkeley, where he directs several state and federal grants in curriculum development and teacher education. He is always looking for new technologies that extend students' capabilities to explore their world.*

Harald Berndt *is a Research Specialist at the Forest Products Laboratory, University of California at Berkeley, where he conducts research on the nature and properties of wood and artifacts conservation. He is especially interested in the potential of computers for data acquisition, storage, and analysis, as well as for education.* ★

ASTRONOMY ORGANIZATIONS AND SUPPLIERS OF AUDIOVISUAL AND OTHER TEACHING MATERIALS

by Andrew Fraknoi
Foothill College &
The Astronomical Society of the Pacific

©1995, Andrew Fraknoi
Astronomical Society of the Pacific
390 Ashton Ave., San Francisco, CA 94112

Below we list nonprofit organizations and commercial companies that produce educational materials, hold meetings that feature programs in astronomy education, or provide other services related to astronomy education. Note that the information in this list (compiled in early 1995) is subject to constant revision: not only do addresses change, but companies often go out of business, or change the items they carry. Whenever possible, we have listed telephone numbers so you can call in advance for current information, catalogs, and ordering policies.

Abrams Planetarium, Michigan State University, East Lansing, MI 48824 (517-355-4676). Publishes a monthly *Sky Calendar*, which is an excellent resource for teachers at all levels.

American Association of Physics Teachers, Business Office, 1 Physics Ellipse, College Park, MD 20740 (301-209-3300). This is a professional society for those who teach physics in college and high school. They have a catalog of slides and films strips (with a few about astronomy); publish journals and sponsor conferences for educators; and have a committee on astronomy education.

American Association of Variable Star Observers, 25 Birch St., Cambridge, MA 02138 (617-354-0484). An organization of dedicated amateur astronomers who keep track of stars whose light output changes. They have begun to sponsor educational programs and have interesting publications for variable star buffs.

American Astronomical Society, 2000 Florida Ave. NW, Suite 400, Washington, DC 20009 (202-328-2010). The AAS is the professional organization for research astronomers in the U.S. In recent years they have become more active in education and have an education committee, electronic bulletin board, and workshops for teachers at their meetings. Because their programs are changing as we go to press, we suggest you contact them for the current list of activities and coordinators.

Annenberg/CPB Multimedia Collection, 901 E St., NW, Washington, DC 20004 (800-532-7637). Offers a selection of public television programs for sale, such as *Planet Earth* and *The Mechanical Universe*.

Association of Astronomy Educators, c/o Katherine Becker, 5103 Burt St., Omaha, NE 68132. This small organization, an affiliate of the National Science Teachers' Association, encourages and unites K-12 teachers of astronomy. They have a newsletter, meetings during NSTA conferences, and exchange information and ideas informally.

Astronomical League c/o Berton Stevens, Executive Secretary, 2112 E. Kingfisher Lane, Rolling Meadows, IL 60008. This is the national "umbrella" group that brings together amateur astronomy clubs. They publish a newsletter called *The Reflector*, hold national and regional meetings, and encourage their members to get involved in education.

Astronomical Research Network, 206 Bellwood Ave., Maplewood, MN 55117 (612-488-5178). Small company that distributes its own series of rather expensive but good quality CD-ROM's with astronomical images.

Astronomical Society of the Pacific, 390 Ashton Ave., San Francisco, CA 94112 (415-337-1100). Founded in 1889, the ASP is an organization with a special dedication to education that includes scientists, educators, and laypeople among its members. It has a full catalog of slides, software, videos, observing aids, etc. with many superb materials for teaching astronomy; sponsors scientific conferences and workshops for teachers; publishes *Mercury* magazine, and a technical journal, information packets, and a free newsletter on teaching astronomy in grades 3-12 called *The Universe in the Classroom*. (Despite its name, the ASP is a national and international organization.)

Astronomy Magazine, c/o Kalmbach Publishing, P.O. Box 1612, Waukesha, WI 53187 (800-533-6644). *Astronomy* is the largest circulation popular astronomy magazine; Kalmbach also publishes a line of astronomy books for amateurs and student observers; and sells posters and observing aids by mail.

Bullfrog Films, Box 149, Oley, PA 19547 (800-543-3764). A distributor of films about the environment, with a few that relate to astronomy. Prices are high. Call for a catalog.

Center for Astrophysics, Education Dept., MS 71, 60 Garden St., Cambridge, MA 02138 (617-495-9798). The

Center, which combines the Harvard University Astronomy Dept. and the Smithsonian Astrophysical Observatory, is one of the largest astronomical institutions in the world. They have an active education division, which sponsors workshops, creates curriculum materials, develops new ideas in instrumentation for educators, etc. Write or call them for a list of current programs and how you can get involved.

Cobblestone Publishing, 7 School St., Peterborough, NH 03458 (800-821-0115; 603-924-7209). Publishes *Odyssey*, the only astronomy magazine for children.

Committee for the Scientific Investigation of Claims of the Paranormal (CSICOP), P.O. Box 703, Buffalo, NY 14226 (716-636-1425). An organization of scientists, educators, magicians, and other skeptics that works to inform the public about the rational perspective on such pseudosciences as astrology, UFO's, etc. Publishes The *Skeptical Inquirer* magazine, full of great debunking articles, and holds meetings and workshops around the country. A related publishing house, Prometheus Books, issues outstanding skeptical books.

Coronet Films and Video, P.O. Box 2649, Columbus, OH 43216 (800-777-8100). This major distributor of science films has recently re-organized; check with them about what titles are available.

Finley-Holiday Films, 12607 E. Philadelphia St., P.O. Box 619, Whittier, CA 90608 (800-345-6707). Commercial company that produces and distributes videotapes and slide sets on space related subjects; many in cooperation with the Jet Propulsion Laboratory. Their caption materials are usually too brief to help beginning teachers, but their prices are quite inexpensive.

Griffith Observatory, 2800 E. Observatory Rd., Los Angeles, CA 90027 (213-664-1181). An observatory and planetarium that publishes a small magazine called *The Griffith Observer*, with a focus on the history of astronomy. One of their astronomers, John Mosley, publishes updated listings of astronomy software; write to him for details.

Hansen Planetarium, Publications Dept., 1845 South 300 West, #A, Salt Lake City, UT 84115 (800-321-2369). Has an excellent line of inexpensive slides, posters, gift items in astronomy; produces planetarium shows for national distribution. Prefers to sell wholesale to distributors; many of their materials are available from places like the Astronomical Society of the Pacific. Call for current policies about ordering directly.

International Dark Sky Association, c/o David Crawford, 3545 N. Stewart, Tucson, AZ 85716. Small non-profit organization devoted to fighting light pollution and educating politicians, lighting engineers, and the public about the importance of not spilling light where it will interfere with astronomical observations. They have excellent information sheets for teachers, students, and activists.

Jet Propulsion Laboratory, Teacher Resource Center, Mail Stop CS-530, 4800 Oak Grove Dr., Pasadena, CA 91109. Has a series of videotapes and slide sets relating to JPL missions available very cheaply for instructors who write in on school stationery.

JLM Visuals, 1208 Bridge St., Grafton, WI 532024 (414-377-7775). Small company organized by K-12 teachers; distributes science slide sets, with a few worthwhile astronomy sets.

Lawrence Hall of Science, University of California, Berkeley, CA 94720. This science education research institute sponsors programs for teachers, publishes excellent curriculum materials, and offers training workshops in using them. For a free catalog call Eureka Publication Sales at 510-642-1016; for curriculum materials in the GEMS program, call 510-642-7771; for information on opportunities for teacher education, call 510-643-5082.

Learning Technologies, Inc., 59 Walden St., Cambridge, MA 02140 (800-537-8703). This company makes the StarLab portable planetaria, and a series of inexpensive educational materials first developed in Project STAR at the Center for Astrophysics. These include an excellent spectroscope, a telescope kit, and more. Ask for a catalog.

Lunar and Planetary Institute, Order Dept., 3600 Bay Area Blvd., Houston, TX 77058 (713-486-2172). This research institute produces several specialized slide sets on solar system phenomena, as well as technical conference proceedings.

NASA CORE (Central Operation of Resources for Educators) Lorain County JVS, 15181 Route 58 South, Oberlin, OH 44074 (216-774-1051 x 293 or 294). A relatively new service to provide NASA audiovisual materials for teachers at very reasonable prices. Ask for a catalog, but be prepared for a confusing jumble of sheets whose descriptions of items are of widely varying usefulness. To be fair, this is a recent operation, their heart is definitely in the right place, and they seem to be getting better with time.

NASA's Education Division (Elementary & Secondary Education Branch, Code FEE, NASA Headquarters, Washington, DC 20546; 202-358-1518) Produces a wide range of materials for teachers and offers workshops and other programs. Programs are generally offered at one of the NASA centers around the country; each center also has a Teacher Resource Center where materials can be obtained, copied, or borrowed. Educators are encouraged to contact the NASA center near them (see list below) for current information about what is available. See also the Jet Propulsion Lab listing above and the Space Telescope Science Institute below, which probably have the information of greatest interest to teachers of astronomy.

NASA Ames Research Center, Teacher Resource Center, M.S. T12-A, Moffett Field, CA 94035 (415-604-3574).

NASA Goddard Space Flight Center, Teacher Resource Lab, Code 130.3, Greenbelt, MD 20771 (301-286-8570).

NASA JFK Space Center, Educators Resources Lab, Code ERL, Kennedy Space Center, FL 32899 (407-867-4090).

NASA Johnson Space Center, Teacher Resource Center, Code AP-4, Houston, TX 77058 (713-483-8696).

NASA Langley Research Center Teacher Resource Center, Virginia Air and Space Center, 600 Settler's Landing Road, Hampton, VA 23669 (804-727-0900).

NASA Lewis Research Center, Teacher Resource Center, M.S. 8-1, 21000 Brookpark Rd., Cleveland, OH 44135 (216-433-2017).

NASA Stennis Space Center, Teacher Resource Center, Building 1200, Stennis Space Center, MS 39529 (601-688-3338).

NASA Marshall Space Flight Center, Teacher Resource Center, US Space and Rocket Center, Huntsville, AL 35807 (205-544-5812).

National Geographic Society, Educational Services, 17th and M St. NW, Washington, DC 20036 (800-368-2728). Produces some audiovisual materials on astronomy. Call for a catalog.

National Science Teachers' Association, 1840 Wilson Blvd., Arlington, VA 22201 (1-800-722-NSTA or 703-243-7100). An important resource organization for teachers in grades K-12. Has a number of journals and newsletters and holds regional and national conferences. They have a sometimes active branch called the Association of Astronomy Educators, which organizes sessions at NSTA meetings. Their catalog has a number of useful astronomy education materials.

National Space Society, 922 Pennsylvania Ave. SE, Washington, DC 20003 (202-543-1900). An organization of space exploration enthusiasts and advocates (part of it was formerly known as the L-5 Society.) Publishes a magazine, has meetings, offers hotlines to hear about Shuttle launches, and has other activities through its regional affiliates.

Optical Data Corp., 30 Technology Dr., Warren, NJ 07059 (800-248-8478). Makes expensive but essential videodiscs on astronomy and planetary explorations.

PBS Video (800-328-7271, 800-343-4727). After many years of being quite disorganized, public TV stations have contracted with a firm called Video Trackers to handle the distribution of some of their materials to the public. They are the firm that answers when you call the above numbers. If you know a title you want, they can be quite helpful, and will even refer you to other companies if they don't carry the title. But be warned; not all PBS offerings are available from them. You can also try the customer information number at PBS which is 800-424-7963. (The Astronomical Society of the Pacific, see listing above, is also a good source for PBS shows relating to astronomy. For NOVA programs, see WGBH below.)

The Planetary Society, 65 N. Catalina Ave., Pasadena, CA 91106 (818-793-1675). Large national membership organization founded by Carl Sagan, Bruce Murray, and others; lobbies for more planetary exploration and SETI; publishes a colorful magazine and has a catalog of reasonably priced slides, videos, & gift items.

Royal Astronomical Society of Canada, 136 Dupont St., Toronto, Ontario M5R 1V2 Canada (416-924-7973). An organization of amateur and professional astronomers operating through a number of regional centers in Canada. Publishes a journal, a newsletter, and a widely praised annual Handbook for serious sky observers. Many of the RASC Centers have active education programs.

Science Graphics, P.O. Box 7516, Bend, OR 97708 (503-389-5652) Small company founded by a former planetarium director that produces somewhat expensive, but very high quality slides for teaching astronomy and geology. Their catalog is well worth requesting.

Sky Publishing, P. O. Box 9111, Belmont MA 02178 (800-253-0245). This company publishes *Sky & Telescope*, the premier magazine for serious amateur astronomers. Call them for their excellent catalog of atlases, sky observing software, and other observing and teaching aids. They also publish a growing line of superb books on astronomical topics.

Space Telescope Science Institute, Education Office, 3700 San Martin Dr., Baltimore, MD 21218. With the success of the repaired Hubble Space Telescope, NASA is expanding the role of the Institute in education. As we go to press, the precise service that will be offered is still being discussed, but the Institute expects to provide workshops, educational materials, and support for programs around the country. Call the main number at the Institute, 410-338-4700, and ask for the education office.

Virtual Reality Labs, 2341 Granador Court, San Luis Obispo, CA 93401 (800-829-VRLI or 805-545-8515). Distributes a variety of astronomical software, including those that let you "walk around" on other worlds.

WGBH-TV, the Boston public television station which produces the NOVA science series is now (at long last) slowly making NOVA episodes available to teachers and the public at reasonable prices. While, as of Spring 1995, they do not have a catalog, you can call with the name of a particular episode and they can tell you whether it is available. Call 1-800-255-9424.

Willmann-Bell, P.O. Box 35025, Richmond, VA 23235 (804-320-7016). Small publisher dedicated to producing specialized books and software for astronomical observers.

Young Astronaut Council, 1308 19th St., NW, Washington, DC 20036 (202-682-1984). Through thousands of local chapters around the country, the Young Astronauts distribute educational materials, and encourage students in grades K-9 to get involved in space-related activities. Some of their activities involve astronomical ideas or projects.

Zephyr Services, 1900 Murray Ave., Pittsburgh, PA 15217 (800-533-6666) Produces and distributes a wide range of specialized astronomical software. Ask for catalog.

NOTE: See the resource listing of national projects in astronomy education for other groups and institutions that have more specialized activities for teachers of astronomy.

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Announcing

The Universe at Your Fingertips:

An Astronomy Activity and Resource Notebook

Edited by Andrew Fraknoi, et al.
Published by the Astronomical Society of the Pacific
Supported by a grant from the National Science Foundation

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AN ASTRONOMY ACTIVITY AND RESOURCE NOTEBOOK
PROJECT ASTRO

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THE UNIVERSE IN THE CLASSROOM project is supported in part by grants from the sponsoring societies, the V.M. Slipher Fund of the National Academy of Sciences, AUI/Nat'l Radio Astronomy Observatory, Lockheed, and Apple Computers.

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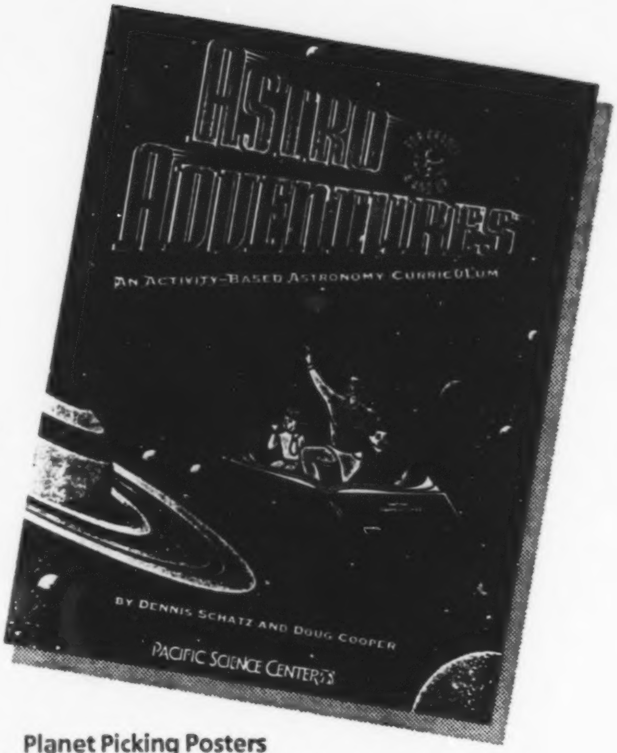
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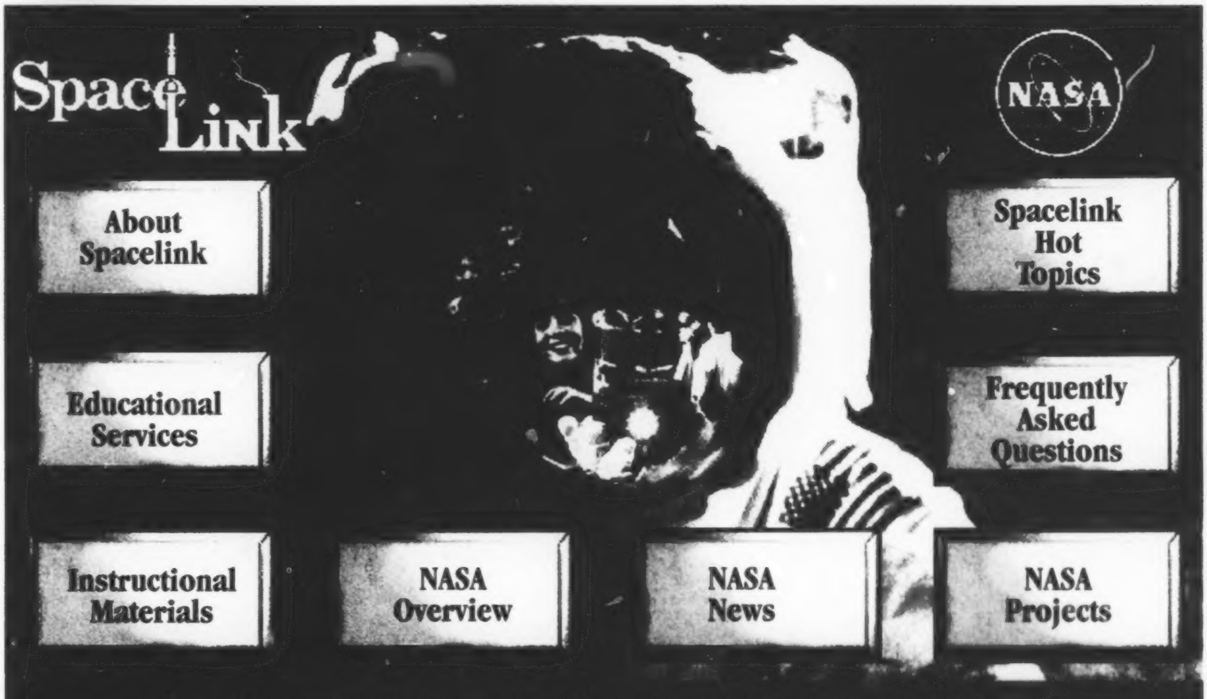

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THE UNIVERSE AT YOUR FINGERTIPS

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We welcome your comments and suggestions on this edition of *The Universe at Your Fingertips*. Please send your feedback to Project ASTRO, Astronomical Society of the Pacific, 390 Ashton Avenue, San Francisco, CA 94112. Or fax to (415) 337-5205.

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Suggestions, corrections, and areas for improvement (please include page numbers for corrections):

(Over)

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